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Lloyd's Register Technical Association

CONVERSIONS TO LIVESTOCK CARRIERS

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CONVERSIONS TO LIVESTOCK CARRIERS

by S. T. Skraastad

SYNOPSIS

Conversion to livestock carrier has become a specialized field developed in step with a steadily increasing demand for this type of vessel and the design considerations include animal care, structural aspects and the application of some animal psychology.

Alterations to the existing ship structures in connection with conversions will be subject to classification approval. However, the Society has also been involved with appraisal and feasability studies of a number of pen stuctures proposed during the last years, recommending standards for acceptance, and this paper outlines some of the aspects to be considered, with brief comments on facilities not subject to classification.

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1. INTRODUCTION

The transport of livestock by sea is traditionally a short-sea trade served by purpose built ships ranging from small all-livestock carriers to combined passenger/general cargo/livestock ships, the first pupose-built all-livestock carrier to LR class being the cattle carrier "ALONDRA" completed 1958, currently in service as "HEREFORD EXPRESS". It is only in the last decade or so that the opening of new markets has led to a rapidly increased demand for deep sea transport facilities, and in the same period the trend has been to provide the required tonnage by conversions rather than purpose built ships. The Society's records do, in fact, indicate that less than ten small purpose-built ships have been completed since 1965 while more than eighty conversions to all-livestock carriers have been effected, and the first recorded conversion to the Society's Class is the former passenger/cargo vessel "ALBERTO DODERO" converted in 1969, now named "ETAIWI 1".

Apart from classification requirements and compliance with international statutory regulations, livestock carriers will also generally require to comply with the provisions of the national regulations for the carriage of livestock by sea issued by the authorities in the countries where the animals are handled. The regulations are primarily concerned with animal welfare by setting standards with respect to access, pen dimensions and arrangements, protection, ventilation, fodder and water supplies, lighting, drainage, care of livestock on board, strength of pens, ship stability etc. (Ref. 1).

TYPES OF SHIPS

The Society's records show that some 80 converted ships operate today and that about 70% of these are conversions from general cargo ships, 12% from Ro-Ro ships and 12% from tankers. The remaining 6% being conversions from passenger ships, ferries and a bulk carrier.

2. STRUCTURAL CONSIDERATIONS

2.1 General

Hull structural considerations in connection with a conversion involve the support and integration of pen structures, fodder and water storage compartments, spaces for power supply and fodder/water distribution, waste disposal arrangements, access arrangements, additional crew quarters etc. While most of the above can be verified by simple applicaton of classification rules, the support of pens in particular may require special consideration.

The design and verification of the structural strength of pens will in most cases remain the responsibility of the shipyard carrying out the conversion and the national authority involved, but the Society may require to extend the hull plan appraisal to include also such items if made to form an integral part of the ship structural support system or being of a nature considered to represent a possible hazard to the ship in the event of structural failure.

2.2 Loads

The loads to be taken into account in connection with pen arrangements are:—

(i) self-weight of pen structures and fittings,
(ii) deck covering (cement or other composition),
(iii) animal weight,
(iv) dung,
(v) fodder storage.

The animal load per unit area is defined by national requirements specifying a minimum deck area per animal as a function of average animal weight, and typical load distributions for sheep and cattle are shown in Fig. 1.

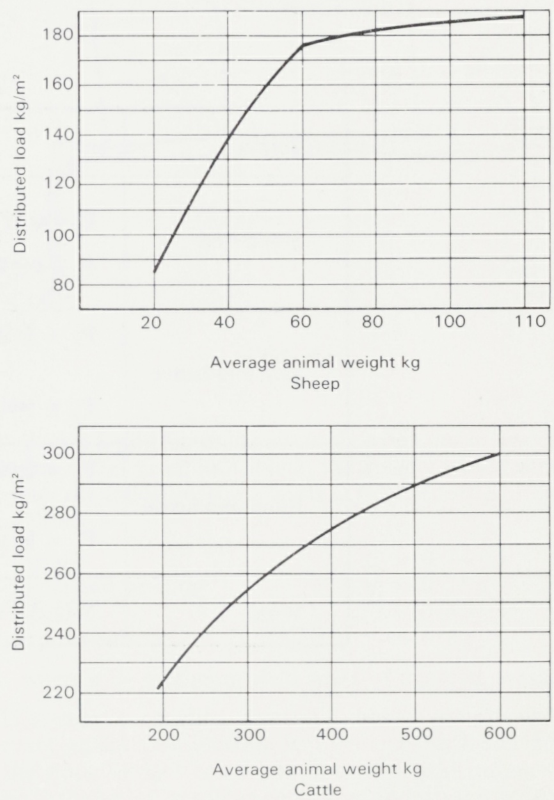


FIG. 1

The weight of dung will only require consideration where pens are not cleaned during the loaded voyage, as may be the case with the carriage of sheep and cattle. For design purposes the weight of dung can be assumed equivalent to about 80% of the consumption of dry fodder as specified by national requirements.

In addition to the static gravity forces, the inertial forces generated by the ships motions during the voyage and wind forces need to be considered, and the examination of the following load combinations is recommended:—

(1) static upright condition
(2) static heel at 30 degrees (minimum criteria)
(3) roll and heave motions
(4) pitch and heave motions
(5) hull girder bending

The ship response data should be agreed upon with the classification society involved, and the values now recommended by Lloyd's Register, where such data is not available for the vessel concerned, are given in Table 1.

The components, normal and parallel to deck, of forces due to gravity and ship motions for load combinations 2, 3 and 4 may be determined in accordance with Table 2. Wind forces are generally recommended to be based on a wind speed of 40 m/s and will be applicable to pen structures above deck only.

For diagrammatic representation of symbols used in Table 2, *see* Fig. 2.

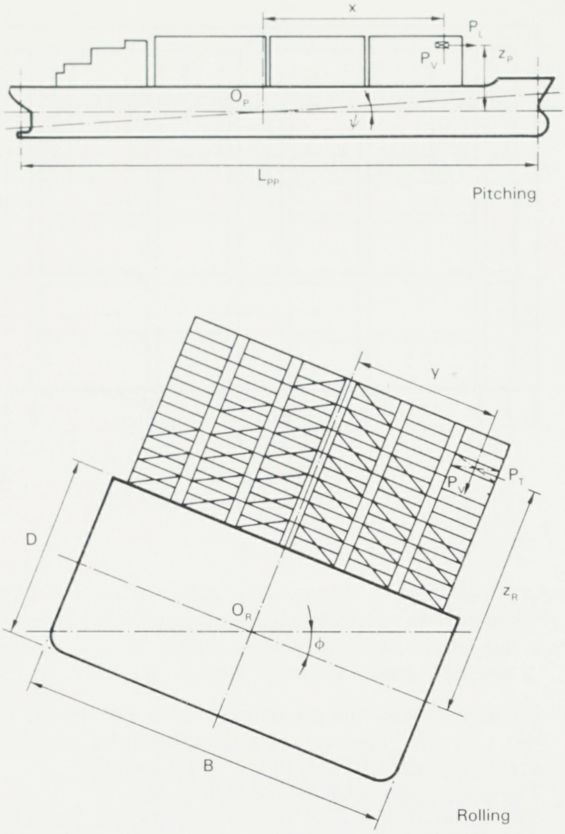
Interactive effects between the pens and the ship in the hull girder bending mode should be avoided as far as possible. Where required, a separate investigation of the resulting forces should be carried out.

Table 1

Motion	Maximum single amplitude	Period in seconds
Roll	$\phi = [14{,}8 + 3{,}7 \frac{L}{B}] e^{-0{,}0023 L_{pp}}$ degrees	$T_R = \frac{0{,}7B}{\sqrt{GM}}$
Pitch	$\psi = 12 e^{-0{,}0033 L_{pp}}$ but need not exceed 8 degrees	$T_p = 0{,}5\sqrt{L_{pp}}$
Heave	$\frac{L_{pp}}{80}$ m	$T_H = 0{,}5\sqrt{L_{pp}}$

Table 2

Source	Forces, in tonnes
Static heel	$P_v = 0{,}87W$ $P_T = 0{,}5W + \text{wind}$
Roll and heave	$P_V = [\cos\phi + 0{,}05 \frac{L_{pp}}{T_H^2} \cos\phi \pm 0{,}07 \frac{\phi}{T_R^2} y]W$ $P_T = [\sin\phi + 0{,}05 \frac{L_{pp}}{T_H^2} \sin\phi + 0{,}07 \frac{\phi}{T_R^2} z_R]W + \text{wind}$
Pitch and heave	$P_V = [\cos\psi + 0{,}05 \frac{L_{pp}}{T_H^2} \cos\psi \pm 0{,}07 \frac{\psi}{T_P^2} x]W$ $P_L = [\sin\psi + 0{,}05 \frac{L_{pp}}{T_H^2} \sin\psi + 0{,}07 \frac{\psi}{T_P^2} z_P]W$
Wind	$8{,}25\ AV^2 \cos\phi \times 10^{-5}$



A = projected side area of the pens above deck, in m^2

B = moulded breadth of the ship, in m

D = moulded depth of the ship, in m

e = base of natural logarithms, 2·7183

GM = transverse metacentric height of the ship in the loaded condition, in m

L_{pp} = length between perpendiculars of the ship, in m

O_P = centre of pitching motion, taken to be at the longitudinal centre of flotation of the ship

O_R = centre of rolling motion, taken to be at the loaded water-line or at half-distance between the loaded water-line and the vertical centre of gravity of the ship where this centre is above the LWL

V = wind speed, m/s

FIG. 2

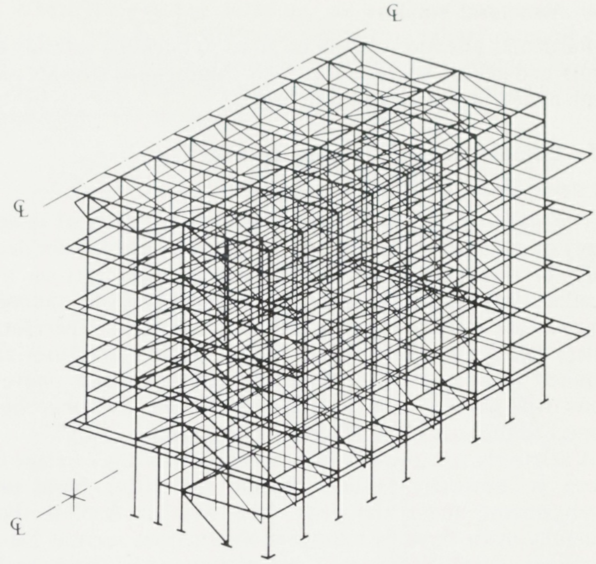


FIG. 3

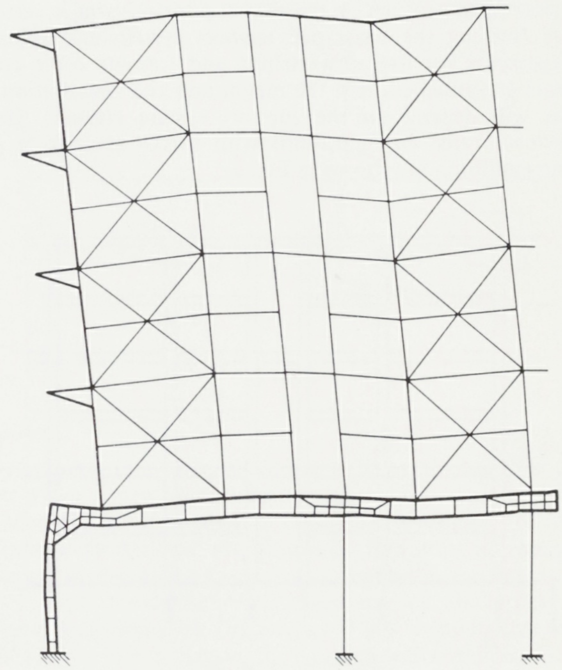


FIG. 4

2.3 **Stresses**

Permissible design stresses are applied to define the load-carrying capability of the supporting structures.

A reliable evaluation of stresses in pen and ship structures will, however, depend on the load assumptions made, the complexity of the arrangements and the refinement of the analysis method employed. While most under-deck arrangements are relatively easily defined, the analysis of large pen structures above deck generally require computer-aided calculations taking due account of the flexural support offered by deck structures in way. A typical example of a 3-dimensional mathematical model is shown in Fig. 3 and the deformed shape of a transverse frame, with deck transverse in line, at 30 degrees of heel in Fig. 4.

Provided a satisfactory analysis is carried out in association with the forces given in Table 2, the Society would generally consider the following stress levels in steel pen structures to be acceptable:—

axial:	$\sigma_a = 0{\cdot}7\,\sigma_y$
axial and bending:	$\sigma_a + \sigma_b = 0{\cdot}75\,\sigma_y$
shear:	$\tau = 0{\cdot}4\,\sigma_y$
equivalent:	$\sqrt{(\sigma_a + \sigma_b)^2 + 3\tau^2} = 0{\cdot}8\,\sigma_y$

where σ_y = minimum yield stress of material considered.

The ships supporting structure should comply with the relevant general classification requirements for loads imposed in the static upright condition. Special consideration will be given to the heeled or rolling condition, and stresses in excess of the above may, under certain circumstances, be accepted.

2.4 **Structural Stability**

Particular attention should be given to buckling stability of struts and pillars subjected to high compressive stresses and plate panels in way of pen supports.

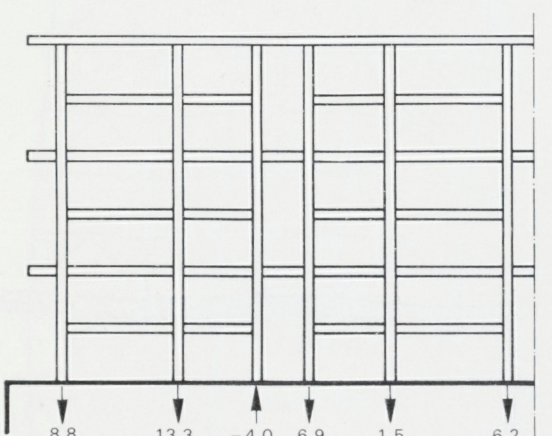
2.5 **Considerations Depending on Ship Type**

General Cargo Ships

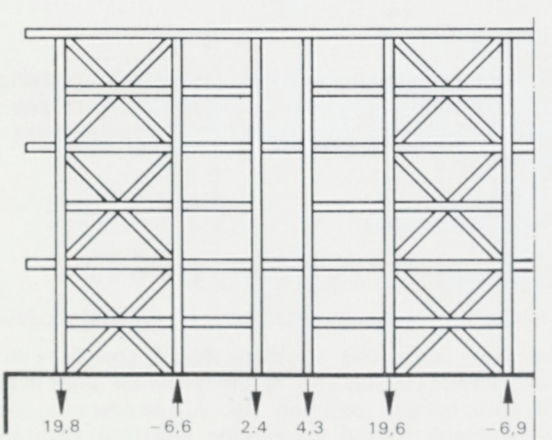
The majority of conversions involve this category of vessel, many of which are relatively small, with pens fitted under deck only, or also with moderate size pen arrangements on the weather deck, resulting in loads not exceeding the standard cargo loads stipulated in the classification rules. Therefore, unless significant modifications to the existing structures are required to accommodate these arrangements, such conversions will generally not present particular problems with respect to the structural integrity of the ship.

A relatively recent trend in connection with the carriage of sheep is, however, to add capacity by fitting large pen arrangements above the deck. The weather deck is then generally made flush by removing obstructions such as hatch coamings, winch-houses etc., and plating-in the hatch openings. In addition the complete or partial removal of transverse bulkheads may be necessary for the optimisation of the under-deck pen arrangements and through-access, thereby impairing the transverse strength of the vessel.

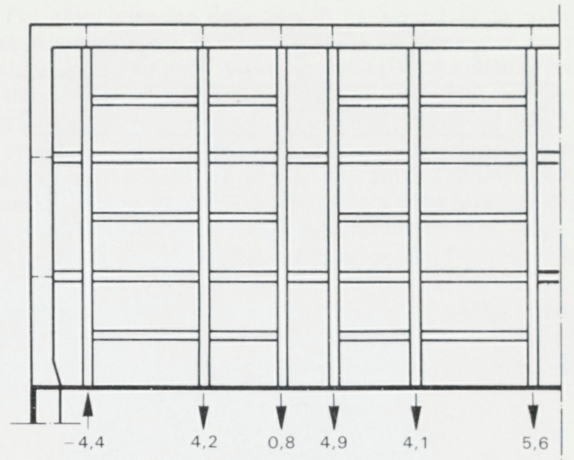
Forces from pens act on the ship at positions where vertical pillars forming the basic pen support system and support arrangements for the athwartships and fore-aft force components are attached, and the magnitude and distribution of forces will depend on the support system chosen. Three transverse frame configurations with forces at deck in the rolling condition are shown in Fig. 5.



(a) Frames spaced 3m



(b) Frames spaced 3m



(c) Frames spaced 3m
Portal frames spaced 6m

Fig. 5

(a) A frame without bracing arrangements. For the size shown this type will, however, require substantial scantlings to accommodate the loads in the racking mode.

(b) The same frame with diagonal bracings.

(c) The same frame with transverse support provided by integrating vent trunks as portal frames thereby avoiding undesirable obstructions within the pens.

In most cases under-deck pillars extending to the double bottom, suitably integrated with pen arrangements in these spaces, will be needed to support the above forces. Such pillars also serve the purpose of minimizing vertical displacement at deck connections, and a typical example is shown in Fig. 6.

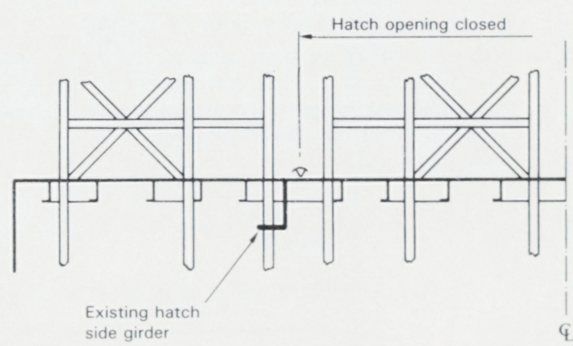


Fig. 6

Where transverse bulkheads are removed the racking strength of the ship may require verification and the under-deck pen arrangements made to incorporate possible reinforcing structures. The fitting of pillars will improve the capability of existing or additional side transverses to support racking forces by reducing the effect of vertical load components, as demonstrated for a complete ring system in Fig. 7.

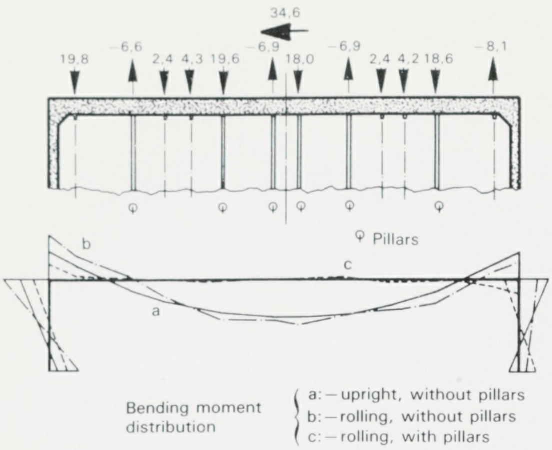


FIG. 7

Depending on the pillar arrangements, the double bottom structure may also require special attention with respect to local strength in way of pillars, as well as overall strength where bulkheads forming double bottom girder supports are removed.

For the size of structures shown above, the support of longitudinal force components will, in the rule, not represent a problem, but expansion joints should be arranged at intervals along the length to prevent primary hull girder bending effects. For larger pen structures see the Section concerned with tanker conversions.

Ro-Ro Ships

Although this type of vessel would seem ideal for conversion to livestock carriers it is only over the last year or so that such ships have appeared in the trade, mainly for the transport of cattle.

The general features of Ro-Ro ships are large, open, cargo spaces without transverse bulkheads extending above the lower tweendeck within the length of these spaces, deck structures suitable for high loads and relatively large built-in tank capacities. The designers task is, therefore, to a great extent simplified, and considerations related to the transverse strength of the ship are in most cases reduced to local reinforcements under the pen corner pillars where not in line with deck transverses, closing of ramp openings generally by welding existing covers and compensation for possible removal of ramps and support arrangements in way. A typical section through a small Ro-Ro ship is shown in Fig. 8 with a single additional light deck fitted.

Where the existing decks are suitable for pen loads from above, a system of continous supporting pillars extending to the double bottom will generally not be fitted, and the bottom structure may thus require special attention, particularly in cases where deeper draught is contemplated.

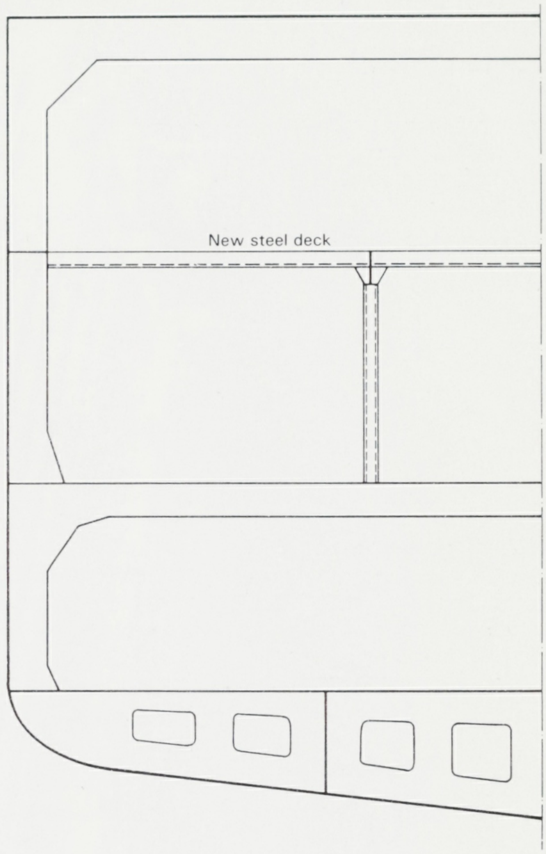


FIG. 8

Tankers

The tanker conversions carried out over the last few years have given a new dimension to animal transport and have without doubt also been a contributory factor to recent extensions to national requirements. The ships are basically engaged in the sheep-trade from Australia and all animal containment arrangements are fitted on deck, the largest with capacities ranging from 90 000 to 125 000 sheep loaded on up to 14 tiers including pens on the weather deck (*see* Plate 1). The pen structures fitted on the vessels now in service are basically of similar design with braced transverse frames at the ends, and longitudinal walkways between the pens. A typical frame with bracings is shown in Fig. 9 indicating the proportions of the structure.

Plate 1 AL SHUWAIKH Livestock carrier—capacity 125,000 sheep

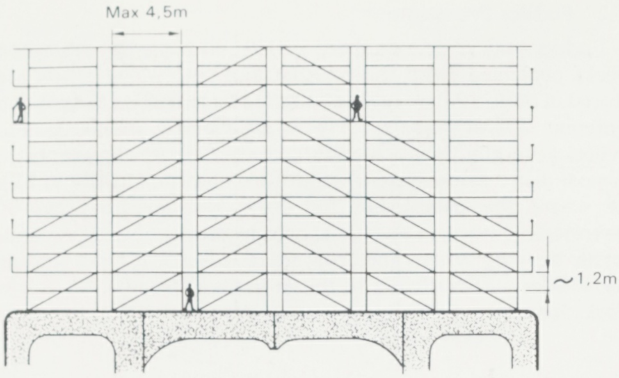


Fig. 9

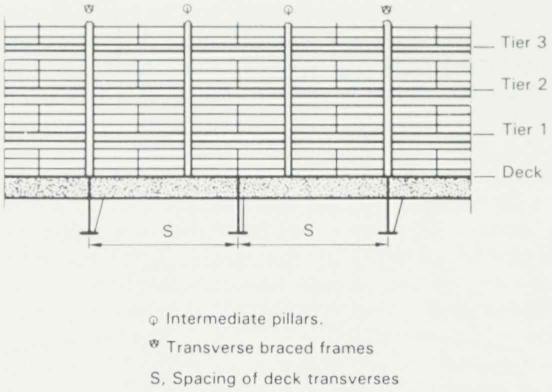


Fig. 11

Some designs feature pen decks without additional vertical supports between the above frames, while others include a system of intermediate pillars (*see* Figs. 10 and 11), and the possible adoption of one or the other design will depend on the strength of deck structures under.

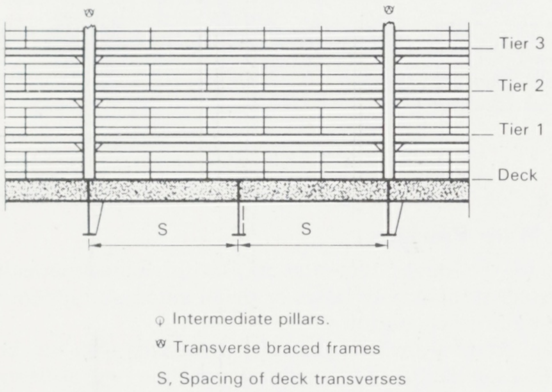


Fig. 10

In connection with tanker conversions it is common to provide for the maximum permissible clear floor area within pens of 40·5 sq.m measuring 4·5 m athwartships and 9·0 m in the fore and aft direction, thus fixing the spacing of braced frames to about 9 m. In order to support the high forces generated in the rolling condition such frames should be fitted in line with the primary supporting transverse deck structures and the arrangements of the vessel intended for conversion should be considered with this in mind. One example of a deck transverse with pen arrangements in way is shown in Fig. 12, where plated areas (shaded) are designed to spread loads from verticals and diagonals. Additional lugs and stiffeners are also indicated and in this connection it should be noted that while the decks of tankers are capable of carrying their design load as distributed loading the local arrangements may not be suitable for high concentrated forces.

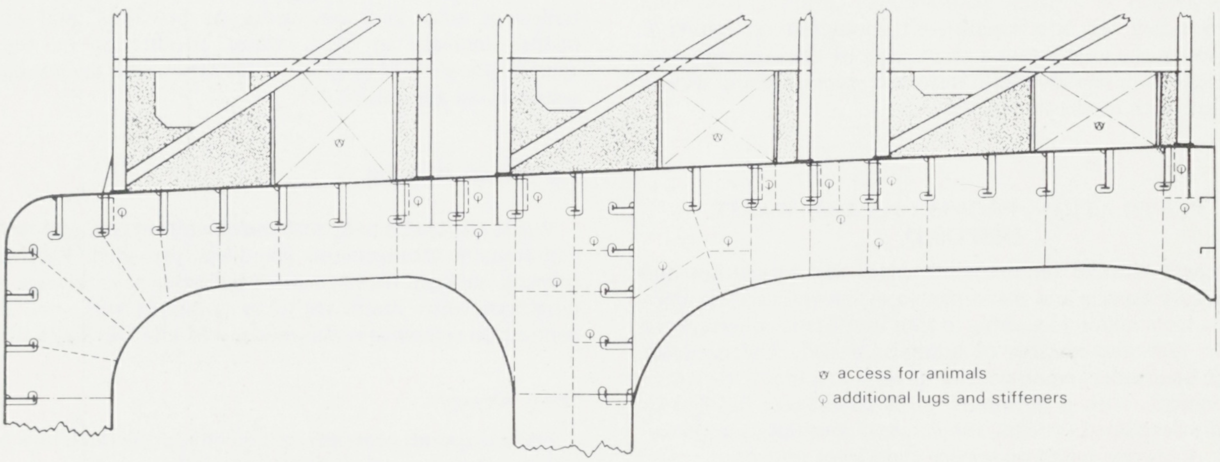


Fig. 12

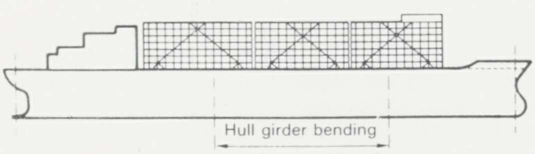


Fig. 13

For the size of pen structures shown, additional support in the fore-aft direction will be needed and one solution is the arrangement of diagonals as shown in Fig. 13, where the pens are divided into three individual blocks along the length of the ship, in order to reduce primary hull girder bending effects. For the vessel considered, each block was provided with four sets of diagonals across the breadth, sufficient to support the maximum pitch and heave forces.

The effect of hull girder bending was separately investigated for the middle block by means of a finite element analysis and the deformed plots for the maximum hogging and sagging conditions are shown in Figs. 14 and 15 respectively.

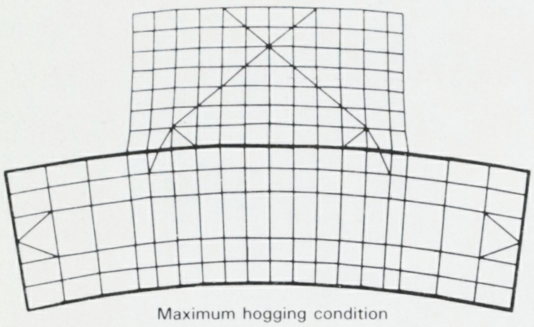


FIG. 14

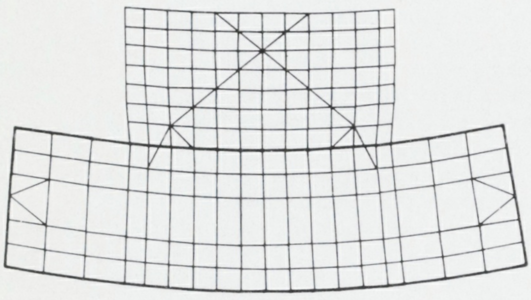


FIG. 15

The stresses in a given arrangement, resulting from hull girder bending, will be a function of the longitudinal rigidity of the ship. In the above case a shortening of the existing vessel provided a high inertia/length ratio and excess midship section modulus, with moderate stresses.

3. VENTILATION, PROVISIONS AND WASTE DISPOSAL

Detailed national requirements cover the ventilation and animal care aspects and the implementation embraces systems ranging from manual handling to fully automatic equipment to suit the type and number of animals carried. The need for reliable mechanical equipment to operate in a highly corrosive environment, with a minimum of maintenance, has led to specially developed systems, subjected to continuous improvements. A process based on service experience returns.

3.1 Ventilation

Mechanical ventilation is required for fully or partially enclosed spaces and for multi-tier open pen structures on deck, where the width exceeds 18 m, although it is normally provided also for smaller arrangements. The number of air changes per hour depends on the clear height of the individual spaces, and the arrangement of pens should be such that the ventilation is not interfered with.

Upper deck penetrations may require compensation for loss of continous deck material.

Where trunks are used to support pen structures, due consideration should be given to corrosion protection and access for maintainance of the protection.

3.2 Fodder Provision

Fodder may be hay or sheep pellets, with the hay stored on decks protected from the weather and sea, while pellets are stored in bulk, and are now required to be carried in at least two different compartments. Hay is distributed manually and pellets generally by semi- or fully automatic arrangements. A typical distribution system is shown diagrammatically in Fig. 16 where the pellets are fed from the main storage to intermediate storages above the pens by means of a conveyor or an air blowing system and from there to vertical pipes leading the fodder automatically to the individual troughs, or to the decks for manual distribution to troughs.

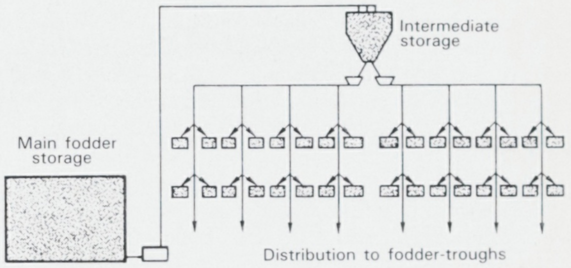


FIG. 16

3.3 Water Provision

As for the fodder, the water may be distributed manually to the water troughs with hoses or by an automatic system with float water-level control.

The fresh water is generally produced by on board desalination plants, the vacuum evaporation type utilizing the heat from the main engine cooling water and/or exhaust gases being common. The capacity of the desalination plant will therefore depend on existing sources of heat, unless additional boilers or other heat generators are provided, and where a further increase in fresh water production is required consideration could be given to the fitting of a reverse osmosis system as an alternative.

3.4 Waste Disposal

Waste disposal is to be suspended while in port and sufficient containment arrangements should be provided. Further, the relevant national requirements for discharge of sewage within territorial water limits are to be complied with, and in this connection reference is also made to MARPOL 73/78 (Ref. 2).

Dung Disposal

Dung disposal, generally carried out during the return ballast voyage, is a manual or semi-automatic operation. A typical under-deck arrangement is shown in Fig. 17a, where the dung is led overboard from each deck by means of a vertical conveyor in association with longitudinal conveyors at decks.

Disposal of Liquid Waste

Liquid waste may be led to wells or tanks of sufficient capacity for the period the ship is in port and discharged overboard during the voyage by means of pumps or ejectors suitable for semi-solid matter. In the case of pens on and above the weather deck, scuppers leading directly overboard are to be closed and arrangements provided to direct the waste to wells or tanks when in port. One example of a discharge system is shown in Fig. 17b.

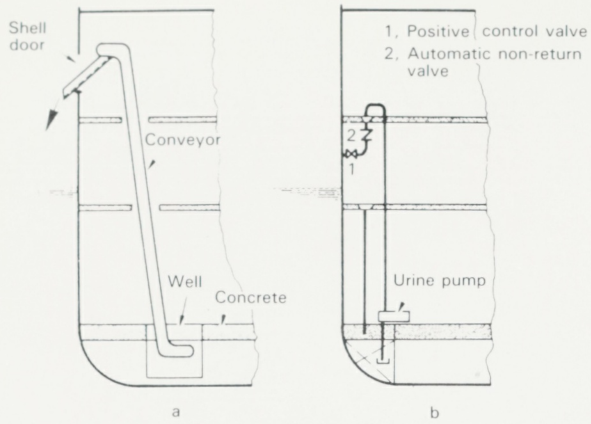


FIG. 17

4. **REFERENCES**

1. Department of Transport, Australia:
Part 43 of Marine Orders, Cargo and Cargo Handling-Livestock.

2. MARPOL 73/78—Annex IV—Regulations for the Prevention of Pollution by Sewage from Ships.

5. **CONCLUSION**

The deep sea trade with voyages of several weeks duration has necessitated the development of extended systems related to animal care and modifications to national requirements, in order to provide better control and improved conditions on board. The types and sizes of ships converted for the deep sea trade also engage the designer in a number of new structural aspects not encountered in connection with smaller ships. A reliable evaluation of forces and stresses in complex pen structures, and the resulting loads supported by the ship may require 3-dimensional analysis methods, and in view of the recent trend towards very large carriers it is recommended to seek early consultance with the classification society involved in order to avoid modifications at a stage when compensation or additional strengthening may result in high extra costs as well as undersirable obstruction to the intended arrangements.

6. **ACKNOWLEDGEMENT**

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NON-DESTRUCTIVE EXAMINATION IN THE SOCIETY

R. Porter

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NON-DESTRUCTIVE EXAMINATION IN THE SOCIETY

by R. PORTER

SYNOPSIS

This paper reviews the principles, applications, advantages and limitations of the basic methods of Non-Destructive Examination (N.D.E.) with particular emphasis on ultrasonic testing. A check list of points to be considered by Surveyors during the assessment of radiographs is included.

The Society's requirements for certification of N.D.E. personnel and the Society's scheme for approval of radiographic establishments are described together with national schemes for personnel certification such as C.S.W.I.P. and SNT-TC-1A.

N.D.E. applications and problems within the Society's Marine, Offshore and Industrial departments are described in turn. Case histories are used, where relevant, to highlight problems that have arisen through inadequate or incorrect applications of N.D.E.

Progress in methods such as acoustic emission and automated ultrasonic testing is reviewed in the final section of the paper.

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1. INTRODUCTION

As the name implies, Non-Destructive Examination, N.D.E. is the collective term applied to those methods of inspection that leave the component undamaged.

The Society's formal involvement with N.D.E. began with the 1934 'Requirements for Welded Pressure Vessels Intended for Land Purposes' which requested that longitudinal and circumferential welded seams be 'X-rayed'. A continually increasing involvement was exemplified in 1981 when the Society became the sole owners of Roentgen Technische Dienst, one of the world's foremost N.D.E. Companies.

Within the Society most Surveyors will be required to assess and accept components that have been subjected to one or more N.D.E. methods. The consequences of inadequate N.D.E. are at best, financially embarrassing, as in those cases where production defects are not observed until the component or structure is in service, or at worse catastrophic, as in those cases where ships and Offshore installations have become casualties through the propagation of undetected flaws.

Applied as part of a thorough Quality Assurance programme, N.D.E. can prevent many unfortunate incidents. It is essential therefore that all Surveyors be aware of the principles, applications and limitations of the major N.D.E. methods.

2. NON-DESTRUCTIVE EXAMINATION METHODS

The N.D.E. methods most likely to be encountered by the Society's Surveyors are Ultrasonic Testing, Radiography, Penetrant Testing and Magnetic Particle Inspection.

Of these methods ultrasonics is probably the most versatile. It can be used for the detection of surface cracks or volumetric defects in metals and in some non-metallic materials.

Radiography can also be used to detect surface and internal flaws and provides the most reliable inspection technique for thin materials, (i.e. <25 mm steel).

Penetrant and magnetic methods should be regarded as being applicable only to the detection of surface defects. Magnetic methods are to be preferred on ferro-magnetic materials.

Each of these methods is discussed in detail in the following section. Additional information regarding the theoretical aspects of the N.D.E. methods can be obtained from the N.D.E. Course notes issued by the Society's Training Centre.

2.1 Ultrasonic Testing

2.1.1 Principles

The basic theory of ultrasonic testing should be well known to mariners. The pulse echo method of water depth measurement has been in use for fifty years, as has the sonar detection of submarines. In this method a pulse of energy in the form of a sound wave is transmitted from a probe. The length of time that elapses between the transmission of the pulse and the reception of a reflected signal can be used to calculate or display the distance between transmitter and reflector assuming that the sound wave velocity in the medium is known.

Most ultrasonic flaw detectors display the information in the form of an 'A' scan presentation, as shown in Figure 1.

On a flaw detector the horizontal distance between the zero point of the scale and the displayed signal is proportional to the distance between probe and reflector. The system is calibrated by adjusting the position on the scale of signals received from reflectors at known distances from the probe. Calibration blocks are used for this purpose.

Since an ultrasonic flaw detector is essentially a two dimensional system it follows that the vertical dimension of the screen requires calibration before signal amplitudes can be used to assess defect significance. This is done by adjusting the amplitudes of signals received from known reflectors such as drilled holes. Calibration of ultrasonic flaw detectors is described in Appendix 1.

For ultrasonic flaw detection it is necessary to interrogate defects in such a way that the transmitted pulse is reflected to a receiving transducer. For the examination of rolled plates, where all defects are likely to be parallel to the plate surface, an examination with a 0° probe is generally sufficient. For the examination of thinner components the selected 0° probe would have separate receiving and transmitting crystals so that the dead zone problem observed at an entry surface with a single crystal probe is eliminated.

With welded components, where defect alignment is uncertain, it is usual to examine a weld from as many directions as possible so that all probable flaws will be detected. A critical weld examination procedure would include probes of 0°, 45°, 60°, and 70°, these being the most commonly used probe angles. It should be noted that the probe angle is measured between the axis of the sound wave and a line normal to the component surface.

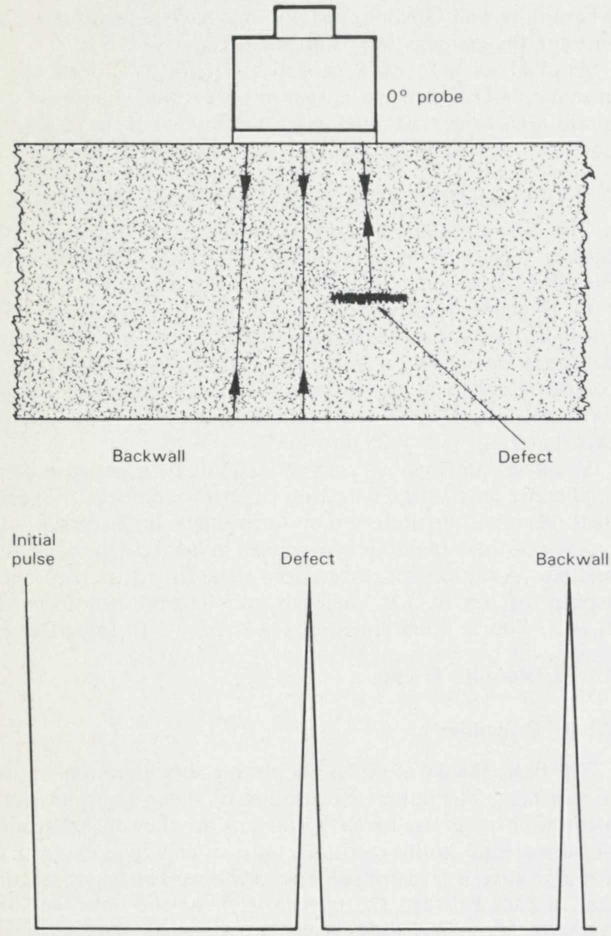


Fig. 1

Ultrasonic testing, 'A' scan presentation

For very thick welds it is necessary to use multi-probe arrays generally in an automated system where individual transducers transmit and receive sequentially.

2.1.2 Applications

The limiting factors which determine the applicability of ultrasonics are the damping capacity of the material and the relationship between the wavelength of the ultrasonic beam and the size of the discontinuity to the detected. Sound waves are propagated more easily through materials with low damping capacity such as steel or aluminium.

It is generally accepted that discontinuities with dimensions greater than ½ wavelength will reflect soundwaves. In carbon or low alloy steels probes with frequencies within the range 2–5MHz are used, giving wavelengths of 1–3 mm. For coarse grained materials and for composite materials such as glass reinforced plastic or concrete it is necessary to use lower frequencies to obtain any penetration.

The nett result of these factors is that the most common application of ultrasonics is for the examination of fine grained metals. It is quite feasible to examine forged turbine discs for the presence of internal flaws less than 1 mm diameter or to make a less sensitive axial examination of a forged shaft several metres in length.

When coarse grained materials or complex materials such as cast stainless steel and spheroidal graphite iron are to be examined it is necessary that the viability of the test be demonstrated on suitable reference blocks containing standard reflectors such as side drilled holes. It is usually necessary to apply probes of lower frequency (e.g. 1 MHz) giving longer wavelengths to overcome the beam scattering effect caused by the material structure.

Applications of ultrasonics likely to be met by the Surveyors include measurement of thickness, which is discussed in more detail later in this section, and the detection of internal or surface flaws in steel weldments, forgings and castings.

Surveyors involved with ultrasonic testing are advised to give attention to the following basic points.

(a) Procedure—formal ultrasonic testing should always be made in accordance with a written procedure available to the Surveyor for scrutiny.

(b) Certification—operators must be in posession of a valid certificate of proficiency (*see* Section 3).

(c) Calibration—Surveyors should check that calibration of range and sensitivity are in accordance with the procedure (*see* Appendix I).

(d) Reporting—reports of completed ultrasonic examinations should be made available to the Surveyor for assessment (*see* 2.1.4.5).

2.1.3 Advantages

The main advantages of ultrasonic testing are:

(a) Access; Battery operated sets can be used wherever an operator has physical access. Components can be examined when only one surface is accessible, automated systems can operate in hostile environments such as underwater or in highly radioactive surroundings.

(b) Health; No hazardous radiations are emitted.

(c) Economy; Costs quoted for ultrasonics are approximately half that of radiography assuming that welds are relatively free from defects. With ultrasonics it is not necessary to hinder production by clearing areas of other personnel, also, it is not necessary to construct radiation-proof laboratories for ultrasonic testing.

(d) Range of application; Welded configurations of irregular cross-section can be examined ultrasonically. With the use of angle probes a greater range of alignments of defects can be detected. Meaningful results can be obtained from axial scans of forged shafts several metres in length whereas the most powerful X-ray apparatus is limited to about 500 mm of steel.

(e) Data obtained; Ultrasonic testing is more likely to detect planar defects such as cracks and will give more information about defect length, breadth, depth and through thickness extent. It is the latter dimension which is most important for fracture mechanics calculations and the dimension which is least obtainable by radiography.

2.1.4 Limitations of Ultrasonics

In view of the increasing application of ultrasonic testing it is worthwhile to consider in some detail the efficacy and accuracy of the method. However, it is important to remember that despite the imperfections of the method, ultrasonic testing represents the best method for the volumetric examination of components greater than approximately 25 mm in thickness.

Defect Detectability. Under perfect conditions, using good procedures, it is possible to detect very small defects ultrasonically. Forgings for aero engines are examined at sensitivity levels where inclusions of less than 1 mm major dimension are rejected. Defects 1.5 mm height × 10 mm length are regarded as detectable during the shop inspection of 250 mm thick weldments for Pressurised Water Reactors. Unfortunately the same sensitivity is not obtained on a reliable basis during the manual inspection of welded components on site. Recent surveys have shown surprisingly low detection rates. Some of the more notable factors affecting detectability are discussed as follows:

(i) Geometrical Features; Operators are liable to be confused by reflections from geometrical features and may attribute signals from weld defects to features such as the weld root, weld reinforcement or weld boundary and vice-versa. Thus defects are more easily detected in straight, dressed butt welds than in as-welded T-joints or nozzle welds.

(ii) Alignment; To detect a smooth planar reflector it is necessary to aim the beam in a direction normal to the plane of the reflector. A mis-alignment of only 10° can allow a defect to remain undetected. This problem is particularly severe in thick welds when using single probe procedures such as that nominated by ASME Code, Section XI.

(iii) Compressive Stress; Compressive stress across a smooth defect can render the defect transparent to ultrasound. For this reason welds should always be examined after any post weld heat treatment.

It is difficult to put a quantitative value on the defect detection probability obtainable with ultrasonics. Most components reported clear by ultrasonic testing will not be subjected to other volumetric examinations. Unless a defect is revealed by subsequent machining or by failure of the component it is liable to remain undetected. On the other hand when specific assessments of detectability are made, the results will be influenced by the prior knowledge of the operator that defects are certain to be present.

The results of two surveys recently published are worthy of attention.

One survey was carried out by the Plate Inspection Steering Committee[1] working for the E.E.C. and O.E.C.D. using test plates provided by the United States Pressure Vessel Research Committee.

This survey was based on results presented on three weldments 204–254 mm thick. The plates were examined by 28 teams from 10 European countries using procedures strictly in accordance with the ASME Code, Section XI. A second set of results was presented for the same test pieces using alternative procedures. The results obtained with the ASME XI procedure were alarming. From the graph shown in Fig. 2 it can be seen that the mean probability for the detection of vertical cracks, 25 mm height, was approximately 50%. For reliable detectability (95% probability), using the ASME XI procedure, a defect height of 50 mm was necessary. The results presented from the alternative procedures as shown in Fig. 3 were more encouraging. The best results were obtained using the alternative procedures originally developed by R.T.D. for the examination of the Biblis reactor in Germany in 1973. These procedures rejected all defects exceeding 10 mm in height, and also rejected many of the smaller defects regarded as acceptable.

(N.B. In Figs. 2 and 3 the horizontal axes represent the size of a defect measured vertically through the weld. Each defect within the three testpieces is represented by one symbol, acceptible defects with heights of less than 10 mm are shown as +, unacceptable defects with heights greater than 10 mm are shown as ●. The vertical axes represent the number of times that a given defect was detected by an inspecting team. A defect detection probability of 1.0 means that a given defect was reported by every team. A value of 0.5 means that only half of the teams reported a defect.

The dotted lines in Fig. 2 represent the upper and lower 95% bands of a confidence limit based on a binomial distribution).

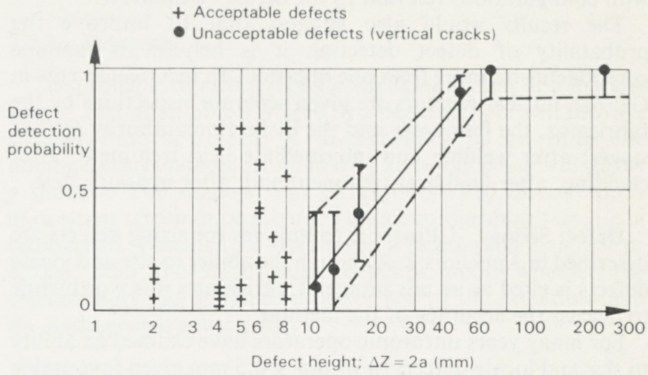


Fig. 2

Defect detection probability using PISC 1-ASME XI procedure

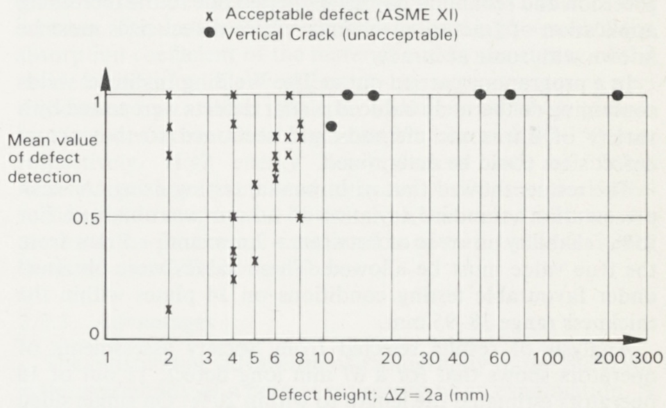


Fig. 3

Mean value of defect detection using alternative procedures

The conclusion reached from PISC 1 was that the ASME XI procedure had scope for considerable improvement and modifications to the procedure since requested by the U.S. Nuclear Regulatory Commission have brought ASME XI into line with the more sensitive ASME Section V. The weaknesses in ASME XI are due essentially to the use of single probe techniques on thick weldments and the insensitive recording levels applied. Welds of thicknesses above 100 mm should either be examined by tandem probe techniques or by high sensitivity single probe techniques.

The relevance of the PISC 1 programme is limited with regard to more conventional applications. Most manual testing is applied to weld thicknesses much thinner than those used in nuclear reactors. The results of a survey carried out recently by the Technical Centre of Finland have also been published.[2] This survey was based on results obtained from 24 plate, tube, T-joint and nozzle welds in material 12–20 mm thickness examined by 28 operators. The results show detection probabilities of about 80% for seam butt welds, 60% for T-joints and less than 50% for nozzle welds. These percentages were based on the defects rejectable to the relevant code, in this case A.D. Merkblatt 5/3. Two root cracks, 30 and 35 mm long in butt welded plate seams were found by 80% of the inspectors. For 100% detection probability in seam welds a defect length of 50 mm was required. The average detection probability for the 10–30 mm long defects in the more complex geometries was reported to be about 50%.

The results of this survey confirm that as-welded joints of complex geometry are more difficult to test than smooth, straight butt welds. This would appear to emphasise the necessity for ultrasonic operators to be qualified on test pieces with configurations relevant to the actual component.

The results would also suggest that to improve the probability of defect detection it is helpful to examine components on more than one occasion. In fact, weldments in German nuclear reactors are given separate inspections by the fabricator, the purchaser and the inspection authority at four stages: after welding and intermediate heat treatment, after cladding, after final heat treatment and, after hydraulic test.

Defect Sizing. Ultrasonic techniques for sizing defects are described in Appendix 2. Although the ability to size and locate defects is cited as an advantage of ultrasonics it is worthwhile to discuss the accuracy of the method.

For many years ultrasonic operators have claimed an ability to size and locate defects to within ± 0.5 mm given favourable conditions and could demonstrate their prowess on reference blocks containing drilled holes. However, relatively few components were dissected to prove the accuracy of the method. Recently the ability of ultrasonics to size defects with precision and reliability has been queried due to the increasing application of fracture mechanics where defect sizes must be known with some accuracy.

In a programme carried out at The Welding Institute[3] welds containing deliberately induced planar defects were tested by a variety of ûltrasonic methods and sectioned so that actual defect sizes could be determined.

The results showed that with manual testing using 'A' scan presentation a standard deviation of ± 3 mm was obtained. For 95% reliability an error of between -7 mm and $+5$ mm from the true value must be allowed. These values were obtained under favourable testing conditions on 14 plates within the thickness range 38–95 mm.

Analysis of results selected from Society assessments of operators shows that for a 67 mm long defect, 11 out of 18 operators estimated the length to within 20%. On single sided welds with the reinforcement present, only 10 out of 32 operators measured defect length to within 20%.

2.1.4.3 **Defect Identification**

In the opinion of the author, ultrasonic testing suffered from being 'developed' by radiographers during its formative years in the 1950's and 60's. Radiographers accustomed to defining the nature of shadows produced by inclusions of doubtful origin ascribed the same ability to ultrasonic testing. Operators were expected to define defect type and were considered to be incompetent if proved wrong. Many Surveyors must have wondered at the black art whereby the green peaks of an ultrasonic flaw detector were translated into cracks, pores or inclusions. At the risk of upsetting some established tenets the following opinions are stated:

(i) a response on an ultrasonic flaw detector indicates that a defect exists at a certain position relative to a probe,

(ii) by observing the effect on the response when the probe is moved in various directions and by scanning the reflector with probes of different angles it is possible to assess the shape of an isolated reflector and to distinguish between isolated cylindrical or spherical volumetric flaws and isolated planar flaws,

(iii) flaws in close proximity to each other defy interpretation as do reflectors whose largest dimension is less than about 5 mm.

Any further evaluation requires either assistance from the metallurgical realm or previous experience of an identical situation. With some knowledge of foundry practice it is possible to make a reasonably accurate deduction of the nature of casting defects. With knowledge of welding procedures it is also possible to identify certain defects such as chevron cracking in submerged arc welds or lack of side wall fusion in M.I.G. welds. Similarly, knowledge of exact weld configuration can be used to identify lamellar tearing, or incomplete root penetration. In other words, the average ultrasonic operator is no more able to identify defect nature than is an experienced foundryman or welding engineer given the same information regarding defect shape, size and position.

Evidence to support the above opinions is given as follows:

(iv) From results of Society assessments it is obvious that most operators prefer not to identify defects. Of the operators who did attempt identification approximately 60% correctly distinguished between planar and volumetric defects. Of the 60% approximately half correctly identified the nature of the defect, i.e. 30% of the attempted identifications were accurate.

(v) In phase 2 of The Welding Institute programme, given that all defects were planar, only 16 out of 28 attempts correctly identified defect nature.

In one additional weld only 15 out of 70 attempts correctly identified a lack of fusion defect which had a through thickness extent of 13 mm.

(vi) In the recent Finnish Survey only 20% of inspectors correctly identified two weld root cracks 30 and 35 mm in length.

Lateral Resolution. A further problem often overlooked by ultrasonic operators is that of lateral resolution. The longitudinal resolution of ultrasonic systems is quite good. With short pulse probes it is possible to resolve two reflectors whose linear distance from the probe differs by only 1 mm. The linear resolution obtained with most conventional probes is about 3–5 mm. The lateral resolution is not so good however. As shown in Fig. 4, two or more defects lying at the same distance from the probe are not resolved if the lateral distance between the reflectors is less than the width of the beam. As the probe traverses from A to B a signal would be observed on the screen at all times, suggesting a continuous defect. The amplitude of the signal would not fluctuate unless the lateral separation was greater than about 70% of the beam width.

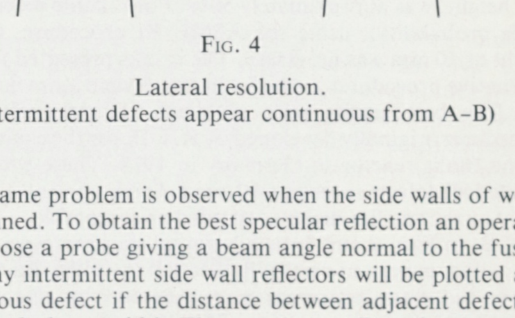


FIG. 4

Lateral resolution.
(Intermittent defects appear continuous from A–B)

The same problem is observed when the side walls of welds are scanned. To obtain the best specular reflection an operator will choose a probe giving a beam angle normal to the fusion line. Any intermittent side wall reflectors will be plotted as a continuous defect if the distance between adjacent defects is less than the beam width. The cumulative effect of two or more reflectors within the beam will give an enhanced signal and persuade the operator to ignore the evidence of smaller, albeit resolved, signals obtained when the defect is scanned with a different angle probe.

Most of the gross over-sizing errors presented by ultrasonic operators can be attributed to ignorance of lateral resolution. Many welders have gazed in disbelief at ultrasonic reports showing enormous defects and many welding engineers have cursed the method when subsequent excavation has revealed intermittent inclusions instead of the expected crevasse.

A recent development which has significantly improved the lateral resolution of ultrasonic testing is known as the synthetic aperture focussing technique, SAFT. However, it will be some years before this system is applied to commercial N.D.E.

Recording A further unsatisfactory aspect of ultrasonic testing is the dependence of the Surveyor upon a written report produced by an operator. To assist in the evaluation of an ultrasonic test it is necessary that reports should include at least the following information:

(i) Identification of weld or component,

(ii) Procedure applied,

(iii) Surface condition of component,

(iv) Personnel identity, qualifications and signature,

(v) Equipment used, including probe types,

(vi) Sketches showing locations and lengths of defects and cross sections of defect,

(vii) Amplitudes of defect signals,

(viii) Statement regarding acceptability of component to given criteria.

The information presented must be such that the examination can be repeated using exactly the same technique so that the results can be verified.

Results produced by automated systems require either specialised knowledge before interpretation can be attempted or further evaluation by manual operators.

2.1.5 Ultrasonic Thickness Measurement

Two ultrasonic methods are widely used for ultrasonic thickness measurement. The calibrated scale of a flaw detector can be used to measure thickness with an accuracy of ± 1 mm. Alternatively, digital thickness meters may be used. Due to the small size and relative ease of calibration of digital meters, most ultrasonic thickness measurement is done with these devices. The principle of operation is slightly different to that of a flaw detector. Crystals oscillating at precise frequencies are used to measure the flight time of an ultrasonic pulse. Material thickness is obtained by counting the number of oscillations occurring between the transmission of a pulse and the reception of a reflected signal. Thickness is displayed in a digital form on the meter of the instrument. On smooth parallel surfaces an accuracy of $\pm 1\%$ over a thickness range of 200 mm is attainable, even when testing underwater.

Digital meters can be used on any material that transmits ultrasound at temperatures within the range $-10°$ to $50°$C provided the equipment has a velocity control. Oxide or paint films on the component surface remote from the probe are not included in the displayed thickness readings, however, laminations or inclusions will give apparently false readings of less than the total plate thickness. Special probes are available for use at higher temperatures.

For ultrasonic detection of pitting or scouring it is obvious that the probe must be placed exactly opposite the corrosion. It is possible to detect corrosion pits a few millimetres in diameter if the probe is correctly located. Any examination made on a grid basis requires an element of fortune if local corrosion is to be detected.

The great problem with digital meters is to obtain a steady reading where an uneven surface is located either beneath or opposite the probe. Indeed, the unfortunate tendency is for operators to move the probe position until a steady reading is obtained, in all probability moving the probe away from the very corrosion which is being sought.

2.2 Radiography

2.2.1 Principles

The principle of radiography is the same as that of a shadow graph. Just as an object placed in a beam of light will throw a shadow onto a screen, a discontinuity in an otherwise homogeneous material irradiated by an X-ray beam will throw a shadow. The shadow may either be viewed directly on a fluorescent screen or be recorded on a photographic film, i.e. a radiograph. Whether the shadow on a radiograph is lighter or darker than the background depends upon whether the discontinuity has absorbed more or less of the radiation than the homogeneous material.

2.2.2 Applications

Radiography is used for the detection of internal and surface defects in welds, castings and small forgings. Any materials that can be penetrated by radiation can be examined. Materials examined include steels, copper alloys, aluminium, plastics and concrete. The thickness that can be examined is governed by the absorption coefficient of the material and by the energy of the incident radiation. Conventional X-ray sets can examine steel thicknesses up to about 100 mm, Iridium and Cobalt gamma ray isotopes cover the ranges 10–75 mm and 40–150 mm respectively. High energy X-ray devices such as Linear Accelerators have been used to examine 500 mm thick steel sections. At the other end of the range, micro-focus X-ray sets are used for panoramic examination of butt welds in 3 mm thick, 40 mm O.D. boiler tubes.

2.2.3 Advantages

The outstanding advantage of radiography to the Surveyor is the availability of a permanent record of an examination. A record that is fairly easy to interpret provided that the basic rules of interpretation as discussed later in this section are followed.

Radiography also has the advantage that the true extent of inclusions and clusters of porosity can be measured. Unfortunately the through thickness extent of defects is not readily assessed by radiography.

2.2.4 Limitations

(a) **Health Hazard.** One of the most serious disadvantages of radiography is the health hazard caused by ionising radiations. Before site radiography can take place the surrounding area must be cleared of personnel which, if not planned for, causes delays to construction. The cost of radiation proof exposure rooms is also a significant economic factor.

(b) **Crack Detectability.** The most serious technical disadvantage of radiography is its limited detection capability for planar defects such as cracks.

The factors having the greatest effect on crack detectability are:

(i) component thickness relative to crack extent,

(ii) alignment of defect relative to direction of radiation, and

(iii) width of separation between crack faces.

The effect of component thickness has been demonstrated at Crawley Laboratory. A radiograph of a section of a steel forging 11 mm thick revealed 54 cracks in one area. A radiograph of the same section when placed on a steel plate 29

mm thick revealed only 18 cracks. (The inability of radiography to detect planar defects in thick welds is exemplified by the fact that radiography of welds in reactor pressure vessels is not a mandatory requirement in the Federal German Republic.)

The effect of crack alignment has also been demonstrated at Crawley. A section of a submerged arc weld containing a longitudinal crack has been radiographed with a sequential variation in the alignment of the crack relative to the radiation. The crack is clearly visible through an arc of only 20°. This result was in agreement with those published by Halmshaw[4] who also showed that the separation between crack faces had a measurable effect on detectability. Cracks with separation of 25 μm are visible through an arc of only about 10°.

It is apparent that single shot radiography through the weld axis stands very little chance of detecting planar defects at the weld boundaries, such as lack of side wall fusion, unless the weld has a square edge preparation. It is fortunate for the suppliers of radiographic equipment that most cracks have a substantial vertical component. However, some cracks, notably chevron cracks, hydrogen induced cracks, sub-cladding and through cladding cracks have shown an almost total reluctance to appear on radiographs.

The chances of detecting cracks by radiography can be improved by image enhancement techniques based on those used to improve photographs of planets taken from space probes. Radiographic films contain more information than the eye can discern; a film will discern density differences of only 0.05% whereas the eye can only discern a difference of about 1.5%. Similarly the eye can only discern an edge boundary when the adjoining areas differ by more than 15% in density. Micro-processors can be used to digitise the density information available on a film. The technique is to scan an area of a radiograph spot by spot. The information may be displayed on a television monitor which is open to the full range of brightness and contrast modification.

(c) **Slag Detectability.** One radiographic oddity that should be noted is the case of the disappearing slag inclusion. The Innershield welding process deposits a slag rich in Barium salts. With X-rays of about 240 kV the absorption of X-rays by the Barium slag is the same as the absorption by steel, the slag inclusions are invisible on the radiograph. If the X-ray energy is less than about 240 kV the slag inclusions absorb more radiation than the steel and the inclusions are visible as areas lighter in density than the weld metal. For X-rays of greater than about 240 kV and for gamma ray isotopes (Iridium = 600 kV, Cobalt = 1100 kV) the slag inclusions are less absorbent than steel and appear as dark areas.

The absorption characteristic of a material is usually expressed as a half value thickness, H.V.T., i.e. the thickness that absorbs half the incident radiation. In steel the H.V.T. rises from 3 mm at 100 kV up to 33 mm at 10 MeV. For Barium slags the H.V.T. appears to be fairly constant at about 8 mm over the commonly used range of X-ray energies. Thus the H.V.T. curves for steel and Barium slags cross over at about 8 mm, i.e. approximately 240 kV. At this point the slag is radiographically invisible.

2.2.5 Interpretation

Most Surveyors will be required to assess radiographs at some stage in their career. Whether or not a Surveyor becomes a good interpreter will depend as much on the character of the Surveyor as on his technical ability. A good interpreter must be in control of the situation and must know what he is looking for. Ideally the Surveyor will view the radiographs at the earliest opportunity and will take part in any discussions regarding the repair of discontinuities. In less fortunate circumstances the Surveyor may be at the wrong end of a long line. By the time this Surveyor views his radiographs the component may have been repaired and moved out of range.

Some Surveyors have had the experience to be confronted with their interpretation of radiographs, which have been questioned, at subsequent official enquiries.

To reduce the possibility of misinterpretation it is recommended that the guide set down below be followed when examining radiographs.

Radiographs should be assessed from two aspects, firstly to judge the quality of the actual radiograph, secondly to assess the quality of the component. Attention should be paid to the following points:

2.2.5.1 Radiograph Quality

(a) **Film Identification.** Each radiograph should be traceable to contract, component, weld seam or part number as appropriate. The manufacturer's name and date of the radiograph should be shown, not necessarily as radiographic images. Location markers must be placed on the component and must appear as radiographic images. Surveyors should be aware of the possibility of falsification discussed later in 4.1.3.(d).

(b) **Film-Screen Combination.** Ultra-fine or fine grain films, ASTM Types 1 or 2, should be used for weld radiography. For maximum sensitivity on applications such as High Energy radiography or on Stainless Steel or Aluminium welds Type 1 film is preferred.

Medium speed Type 3 film is acceptable for examination of steel castings.

Examples of films are:

Type 1, Ultra-fine grain; Agfa Gevaert D2, D4; Kodak M; Du Pont 45, 55.
Type 2, Fine Grain; Agfa Gevaert D7; Kodak A, C; Du Pont 65, 70, 75.
Type 3, Medium Speed; Agfa Gevaert D10; Kodak D.

Most radiographic techniques use thin lead intensifying screens on either side of the film. Salt screens are not permitted for weld examination.

(c) **Film Density.** The density, or darkness, of a radiograph is measured on a densitometer which should be available in any well equipped darkroom. Alternatively, density can be assessed against a calibrated density strip, which is a piece of film of different densities. Defects can be seen more easily when the density difference, or contrast, between the image of the defect and the image of the parent material is greater. The contrast will be increased as the density of the parent material is increased. For this reason a minimum density is always nominated. The ASME Code, Section V, Article 2, requires that the minimum density on a radiograph measured in the area of interest should not be less than 1.8. Higher densities are preferred for low contrast techniques, such as gamma radiography. The maximum density variation permitted by ASME is −15% to +30% from the value measured at the penetrameter.

(d) **Penetrameter, I.Q.I. Sensitivity.** The quality of a radiographic technique is assessed by the use of devices known as penetrameters or image quality indicators, (I.Q.I.). American codes use penetrameters, small shims of the same material as the component placed alongside a weld or on top of a casting (Fig. 5). The thickness of the shim is dictated by the code and is usually 2% of the component or weld thickness. The shim will contain three holes whose diameters will usually be equal to 1x, 2x and 4x, the shim thickness. The code will nominate the 'essential' hole which must be discernible on the radiograph. The designation of the penetrameter, usually equal to the shim thickness expressed in thousandths of an inch,

is displayed by lead numerals at the end of the shim. For most ASME code work the designated penetrameter given in the appropriate table of Section V, Article 2, must be used.

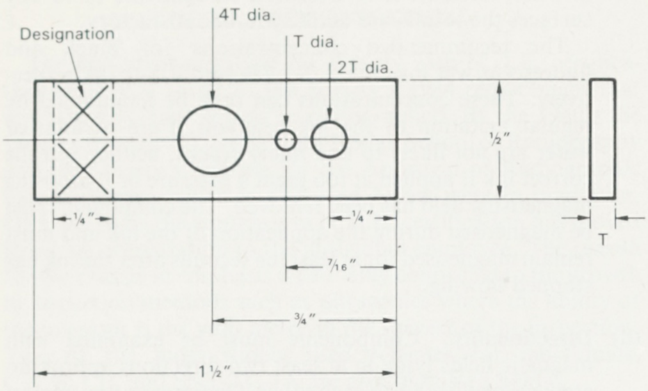


Fig. 5

ASME Penetrameter

Many countries use wire type image quality indicators, (I.Q.I.). These consist of a group of wires of progressively increasing diameter as shown in Fig. 6. I.Q.I. are identified with regard to type, e.g. DIN 62; material of wire, e.g. FE = Steel; CU = Copper; AL = Aluminium; and wire diameter, e.g. International Standards Organisation (ISO) wire Nos. 1–7, 6–12 or 10–16, these being the three groupings available.

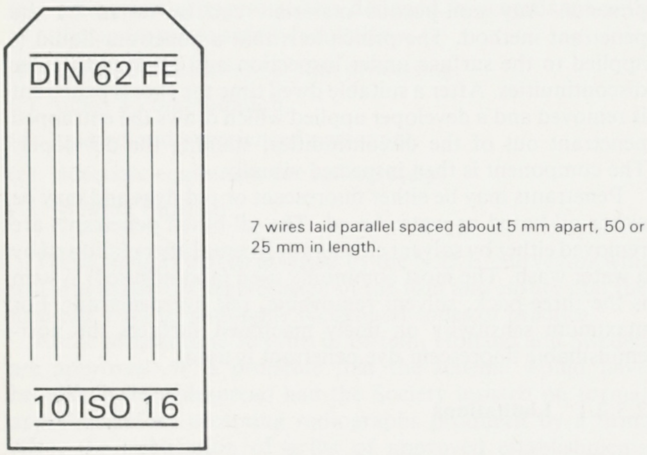


Fig. 6

Example of DIN. I.Q.I. (1962 Standard)

7 wires laid parallel, spaced about 5 mm apart; 50 or 25 mm in length.

ISO DIN 62 wire diameters (mm) are as follows:

No.	1	2	3	4	5	6	7	8
d	3.2	2.5	2.0	1.6	1.25	1.0	0.8	0.63
No.	9	10	11	12	13	14	15	16
d	0.5	0.4	0.32	0.25	0.2	0.16	0.125	0.1

I.Q.I. are placed across a weld seam on the surface of a component *nearest* to the radiation, with the thinnest wire away from the centre of the radiation beam. After exposure and processing of the film some or all of the wires should be discernible on the radiograph. To determine I.Q.I. sensitivity the diameter of the thinnest wire visible on the radiograph is expressed as a percentage of the weld thickness.

For example:

The I.Q.I. shown in Fig. 6 has been used on a weld 25 mm thick. On the processed radiograph three wires are discernible, i.e. wires Nos. 10, 11 and 12. The diameter of wire 12 is 0.25 mm, therefore the I.Q.I. sensitivity is $0.25/25 \times 100\% = 1\%$.

It should be remembered that lower numerical sensitivities demonstrate better radiographic techniques.

For wire type I.Q.I. the following values of sensitivity should not be exceeded when single wall-single image techniques have been applied.

TABLE 1

ATTAINABLE I.Q.I. SENSITIVITIES

Thickness (mm) steel	I.Q.I. Sensitivity %	
	X-Ray	Gamma-Ray
3	2.4	—
6	1.6	—
12.5	1.4	2.4
25	1.2	1.7
40	1.1	1.5
50	1.0	1.3
75	0.9	1.1
100	0.8	1.0
150	0.7	0.9

(e) **Processing.** Films should be free from mechanical or chemical blemishes that may obscure the image. Such blemishes include, fogging, water marks, static, scratches, crimps and false indications caused by screens. Artefacts will usually be visible on the surface of the radiograph when viewed by reflected light, unlike component defects which will only be visible when the radiograph is viewed by transmitted light.

2.2.5.2 Component Quality

Proficiency in defect identification can only be gained by experience. Documents such as BS 499 Pt 3 and BS 2737 are useful references since they contain illustrations of defects found in steel welds and castings respectively. Having identified any defects visible on the radiograph the Surveyor must ensure that the component meets the requirements of the relevant code.

Component quality may be assessed by comparing the radiograph with reference radiographs such as the ASTM E446 radiographs for steel castings or against the IIW reference radiographs for welds. It is the manufacturer's responsibility to provide reference radiographs if required.

It is more usual for acceptance criteria to define the permitted imperfections. ASME acceptance criteria are defined in Section VIII, Division 1, UW 51, as follows:

(i) Planar defects, cracks, lack of fusion, incomplete penetration are not permitted.

(ii) Elongated indications longer than the following values are rejected.

6 mm, for thickness up to 19 mm
1/3 t, for t between 19–57 mm
19 mm, for t over 57 mm.

(iii) Porosity or rounded inclusions are acceptable provided the amount does not exceed that shown in the ASME porosity charts given in Appendix 4 of ASME Section VIII.

2.3 Surface Crack Detection

Stress concentrations are generally greater at surfaces than at internal zones, therefore cracks are more likely to be initiated or to propagate at the surfaces. Correctly applied penetrant, magnetic or eddy current examinations are more likely to detect surface flaws than either ultrasonics or radiography. They can also be applied to fillet welds which are almost impossible to examine by other methods.

Despite the significance of surface defects, crack detection techniques are probably the most mis-used methods of N.D.E. Too often, crack detection methods are discarded completely because volumetric techniques are to be applied. Personnel employed to carry out surface crack detection inspection will usually be the least skilled and experienced members of an N.D.E. team. The recent impact of Quality Assurance programmes has improved the position regarding the training and certification of crack detection personnel but many unskilled personnel are still employed.

Surveyors should be aware of the principles and limitations of the methods as described below.

2.3.1 Magnetic Particle Testing

The magnetic particle method can only be applied to ferro-magnetic materials. The method will detect surface discontinuities and may detect defects lying within a few millimetres of the surface if a suitable technique is used.

The principle of the method is to apply finely divided ferro-magnetic particles to a magnetised area. The particles are attracted to the flux leakages which occur at surface discontinuities. The maximum sensitivity will be obtained when linear discontinuities lie perpendicular to the direction of the magnetic field. Components may be magnetised using magnetic yokes, either permanent or electromagnetic, or by passing an electric current either through the component or in close proximity to the component. Indicators containing simulated defects are available to demonstrate adequate magnetic flux.

2.3.1.1 Limitations

(a) **Arcing.** With current flow methods arcing and burning can occur at contact points. In machined components such as crankshafts and in some low alloy steels, failures have occured as a direct result of cracks growing from contact burns.[5] This method should never be used on finish machined surfaces or on highly stressed components such as crankshafts, rotor shafts or tailshafts. Arcing can be minimised by the use of soft metal braids or tips made from tin-aluminium alloys. For either metallurgical or health reasons the use of copper, zinc or lead tips is discouraged.

(b) **Inadequate Flux Densities.** The recommended flux density[6] of 0.72 tesla is attainable in most steels with an applied field of 2,400 A/m (30 Oersted). Fortunately for inspectors cracks can often be found with applied fields of less than 50% of this value[7].

The most common reasons for inadequate flux densities are:

(i) Poor contact due to dirt, paint, oxide films or mismatch between component configuration and magnetic yoke. (It should be noted that the required lifting powers for permanent magnets and a.c. electro-magnetic yokes are 18 kg and 4.5 kg respectively).

(ii) Excessive distance between prods or between the poles of magnetic yokes. With the prod method a current of 100 A/25 mm prod spacing is required. The distance measured along a surface between the poles of a yoke should not exceed 150 mm. On branch welds in pressure vessels and in node welds in offshore structures this spacing is often exceeded.

(c) **Detection Media Application.** Ferro-magnetic particles can be applied as a powder or as a suspension in water or paraffin. Dry powder can be more sensitive but wet inks are usually more efficient. If the dry powder method is applied in windy conditions to overhead components or to oily surfaces the results are unlikely to be satisfactory.

The recommended concentrations for black and fluorescent wet inks are 2.0–2.7% and 0.2–0.7% respectively. These concentrations can only be maintained by regular agitation of the ink reservoir. Pure paraffin or water are not likely to find many cracks, neither will the correct ink if applied at too great a pressure or if after the magnetising field has been removed. The component must be magnetised during the application of the ink and must remain magnetised for at least ten seconds after the ink has stopped flowing.

(d) **Directionality.** Components must be examined with magnetic fields lying in at least two directions approximately perpendicular to each other. Operators often neglect the second examination.

(e) **Weld Profile** An angle formed by overlaps at the toe of the weld will give a spurious indication. For correct examination for weld toe cracking it is necessary for the weld profile to be blended smoothly with the parent metal.

2.3.2 Liquid Penetrant Testing

Penetrant testing is a means of detecting discontinuities open to the surface in ferrous or non-ferrous materials although magnetic methods are preferred for ferro-magnetic components. Any non-porous materials can be tested by the penetrant method. The principle is that a penetrant liquid is applied to the surface under inspection and allowed to enter discontinuities. After a suitable dwell time the excess penetrant is removed and a developer applied which draws the entrapped penetrant out of the discontinuities, staining the developer. The component is then inspected visually.

Penetrants may be either fluorescent or red dyes and may be either oil-based or water-based. The oil-based penetrants are removed either by solvent cleaners or by emulsifiers followed by a water wash. The most commonly used (and misused) system is the three-pack, solvent removable, red dye penetrant. For maximum sensitivity on finely machined surfaces the post-emulsifiable fluorescent dye penetrant is used.

2.3.2.1 Limitations

(a) **Pre-cleaning** It is essential that the surface area of the component and the crack surfaces themselves are clean before the method is applied. Any fine cracks in components operating under lubricating conditions are liable to be full of lubricant. Likewise, pre-existing cracks in painted components will be filled with paint. A similar problem occurs with bronze propellers whereby any service cracks will be filled with salts as a result of the electrolytic action between the steel hull and the bronze propeller. The best surface preparation consists of machining followed by chemical etching. Peening or shot-blasting should be avoided.

Due to the difficulties of cleaning the crack faces in large components penetrant testing is more likely to be applied to new components than to components in service.

(b) **Excessive Washing** Having filled the crack with penetrant the trick is to avoid washing this dye away when the surplus penetrant is removed. Over washing by direct spray with solvents, by excess pressure with water based systems or by excessive emulsification can remove evidence of cracking.

(c) **Profile** As with the magnetic method it is necessary to blend weld profiles before penetrant testing is attempted. However, with soft metals it is possible to smear the edges of the crack together whilst the profile is being blended.

3. N.D.E. CERTIFICATION

The first involvement of the Society with N.D.E. certification came as a result of the Society's 1934 requirement that welds in pressured vessels be radiographed. By the 1940's the Lloyd's Approved Course at the Kodak School of Radiography and the Society's Scheme for the Approval of Radiographic Establishments which is discussed below were in operation. Over the years the emphasis in N.D.E. certification has moved from the organisation to the individual employee. The reason for the change in emphasis is probably connected to the growth in inspection methods such as ultrasonics where the ability of the operator is the vital factor in the success of the inspection. Two of the most widely used schemes for individuals, C.S.W.I.P. and SNT-TC-1A are also discussed below.

3.1 Society Approved Radiographic Establishments

The earliest assessments under this scheme were made in the days when the Society employed radiologists on a consultative basis. The reports issued by the learned gentlemen provide a fascinating insight into the development of industrial radiography in Britain and the corresponding decline in status of the industrial radiographer over the last 40 years.

In principle the scheme has hardly changed since those days. The Society will give formal approval to any radiographic establishment equipped with:

(a) permanent exposure rooms designed in accordance with the appropriate safety regulations,

(b) darkroom facilities for film processing,

(c) office accommodation,

(d) trained and experienced personnel,

(e) adequate equipment for radiography,

(f) viewing facilities.

These features will be assessed by the N.D.E. Surveyors who will also assess the organisation of the firm and ensure that the firm can work to nationally recognised codes of practice.

At the present time 30 firms in Britain, Holland and Sweden are approved. It is probable that the scheme would have become more widespread had the Society insisted on formal approval before accepting radiographs produced by a firm. Also, the publication of a list of approved establishments would have encouraged the growth of the scheme. So far, the main advantage to an approved firm has been the use of the Society's name for letter heading and advertising purposes.

Most of the British firms approved under the scheme are also approved by organisations such as British Gas, Central Electricity Generating Board, National Coal Board, Civil Aviation Authority and so on. The multiplicity of test house approvals has given rise to the establishment of the National Testing Laboratory Accreditation Scheme, NATLAS. Under this scheme NATLAS organises the assessment of a Laboratory. NATLAS approvals are accepted by most of the organisations mentioned above and the need for multiple assessments is removed.

The Society is to participate with NATLAS and will provide assessors for the scheme.

3.2 SNT-TC-1A

In 1968 the American Society for Nondestructive Testing published Recommended Practice No. SNT-TC-1A for the certification of N.D.E. personnel. Further editions of the document were issued in 1975 and 1980.

The basic principles of SNT-TC-1A are essentially that an employer is responsible for the certification of his own personnel, and that the details of the certification must be acceptable on a buyer/seller basis. The employer is expected to prepare a written practice for his certification programme which must be available for audit by any prospective Client or inspection authority. The results of all examinations made under the scheme must also be available for audit.

The application of in-house certification schemes is obviously open to abuse and SNT-TC-1A certificates have been regarded with some scepticism. Nevertheless, the scheme has some advantages, particularly with regard to cost. It is also possible for a firm to devise training programmes tailored precisely to its own requirements.

Personnel qualify to one of three levels under SNT-TC-1A, as follows:

Level I individuals are the least experienced operators, working to defined procedures and usually supervised by a Level II individual.

Level II individuals should be able to work without direct supervision, calibrating equipment and evaluating results. The Level II should be able to prepare written procedures and to organise and report the results of nondestructive tests.

The **Level III** individual is responsible for the examination of personnel to Levels I and II and is usually responsible for the preparation and designation of inspection procedures to be used by a firm.

The Level III individual may be qualified by declaration from the firm on the basis of ability and experience. Alternatively qualification can be by examination administered either externally or from within the organisation. The ASNT has established an examination leading to Level III qualification. Similarly, the Society's N.D.E. Surveyors have prepared Level III examinations for non-Society personnel. Qualification by examination is mandatory for work to the ASME Code, Section III.

SNT-TC-1A qualifications are used in many countries throughout the world and it is important that Surveyors are aware of the requirements of the scheme.

To be fully acceptable to the Society SNT-TC-1A schemes should be audited on a regular basis.

Auditing of SNT-TC-1A schemes by the N.D.E. Surveyors has shown several recurring problems, namely, absence of a satisfactory written practice, irrelevant or inadequate practical examinations and insufficient documentation of examinations and testpieces.

General requirements for acceptance of these qualifications are as follows:

A written practice for personnel certification in accordance with SNT-TC-1A must be prepared by the employer and be submitted for assessment.

Certificates issued as a result of examination should include the following information:

(a) Serial Number of certificate.

(b) Name and signature of operator.

(c) Name and signature of Level III examiner.

(d) Name and signature of employer.

(e) Date of examination.

(f) Date of expiry.

(g) Methods for which the certification is valid.

(h) Level of qualification in letters and numerals.

(i) Product form, e.g. welds, plates, forgings or castings.

(j) Categories of weld configuration (UT weld testers only).

Examinations for ultrasonic weld testing personnel should include practical examinations in one or all of the following

categories depending upon the degree of acceptance required:

(a) Double sided plate welds.

(b) Single sided pipe welds.

(c) T, K, Y plate node welds.

(d) Variable geometry node or branch welds.

It is preferred that original certificates be embossed and that details of certification be typed on faint-line paper to prevent forgery or alteration.

It will be a requirement that schemes are assessed initially by the Society's N.D.E. Surveyors with surveillance visits at six-monthly intervals. The initial assessment will include a review of the written practice, examination questions and the range of testpieces available for practical examinations. Documentation of personnel qualification records will be checked against Clause 9 of the SNT-TC-1A recommended practice. Similarly the documentation of testpieces and the marking schedule to be applied will also be assessed.

The Society will reserve the right to carry out additional examinations on selected personnel if considered necessary.

The recent trend in Britain is towards independently administered examinations for Levels I and II operators. This could enhance the status of SNT-TC-1A to the point where it becomes dominant over all other certification schemes.

3.3 Certification Scheme for Weldment Inspection Personnel (C.S.W.I.P.)

C.S.W.I.P. is an independent scheme operated by the Welding Institute for a Management Board upon which the Society is represented. Operators in possession of a valid C.S.W.I.P. certificate of competence are generally acceptable to the Society without further assessment.

The following phases of C.S.W.I.P. have been established:

1. Ultrasonic.
2. Radiography.
3. High Energy Radiography.
4. Magnetic Particle and Penetrant Personnel.
5. Ultrasonic Plate Tester.
6. Welding Inspector.
7. Diver-Inspectors.

The phases may be sub-divided according to weld configuration, for example, Ultrasonic Phase I has the following categories:

3.1 Plate welds.

3.2 Pipe welds.

3.7 Constructional T joints.

3.8 Nozzles and variable geometry welds.

3.6 Overall qualification.

The independence of the scheme and the emphasis on practical ability has established C.S.W.I.P. as the most respected certification scheme for N.D.E. personnel.

A National Scheme for certification of N.D.E. personnel in Britain known as P.C.N.—Personnel Certification in Non-Destructive Testing, has been established in an attempt to avoid the necessity for multiple qualification of personnel. The aim is to combine existing schemes such as those organised by C.E.G.B., British Gas and C.S.W.I.P. It is expected that C.S.W.I.P. will become the Specialist Board for welding inspection personnel under the combined scheme. Other Specialist Boards will be established for aerospace, forgings and castings.

3.4 Society Assessments

Assessment of ultrasonic operators began in 1973 when work commenced on the first production platforms for the B.P. Forties Field. At that time there were insufficient operators qualified to suitable National Schemes. The practical ability of each operator was assessed using welded testpieces provided by the Society. The operators ability was graded into one of five levels, listed on site for convenience as follows:

Grade 1 Acceptable for all configurations.

Grade 2 Single sided welds of constant configuration.

Grade 3 Double sided plate node welds, T, K or Y configuration.

Grade 4 Double sided butt welds of constant configuration.

Grade 5 Trainee operator requiring direct supervision.

The written examination given to the first operators was dropped as the irrelevance of theoretical ability to practical ability became apparent.

Between 1973 and 1978 over 500 assessments were made.

Certificates issued were valid for five years and stated that the named operator whilst employed by a named company, would be acceptable to the Society for the examination of welds of a given configuration for work coming under the Societys' survey.

These limitations made it necessary for the operators to obtain less restricted certificates such as those issued by C.S.W.I.P.

In 1974 the N.D.E. Surveyors were asked to assess diver-inspectors employed to monitor offshore installations. A scheme was established for underwater assessments in magnetic particle crack detection, ultrasonic thickness measurement and cathodic potential monitoring. Less frequently, underwater radiography and ultrasonic weld testing were attempted. Notes on these assessments are given in the Survey Procedures Manual, Part J, Addendum D.

By 1980 when the C.S.W.I.P. Phase 7 was established, over 800 diver-inspectors had been assessed.

Assessments of non-Society ultrasonic operators and diver-inspectors are still made by the N.D.E. Surveyors although on a reduced basis.

4. APPLICATIONS OF N.D.E. WITHIN THE SOCIETY

4.1 Marine

4.1.1 Introduction

Experienced Ship Surveyors will appreciate that welds in ships are far more tolerant of defects than are welds in pressure vessels. In fact the volumetric inspection methods such as ultrasonic testing and radiography are only applied for quality control purposes on a spot check basis. There is certainly no requirement for 100% volumetric examination of ship welding. Equally, there is no occasion for complacency regarding the weld quality of modern ships. Improvements in welding processes and the use of notch tough steels have virtually eliminated the brittle fracture mode of failure responsible for the loss of many wartime vessels such as the Liberty ships and the tanker World Concord in 1954. When brittle fracture occurs today it is usually in older vessels. However, the Society has been involved in at least three cases of brittle fracture concerning tankers built in Britain in the 1970's.[8] A common feature in all three cases was that the fractures initiated at gross defects in manual welds; defects that would have been detected had conventional N.D.E. been applied.

The defect at the origin of the fracture in the M.T. *Kurdistan*, Fig. 7 was located in an apparently insignificant weld in the flat ground-bar of the port bilge keel. The starboard bilge keel is shown in Fig. 8.

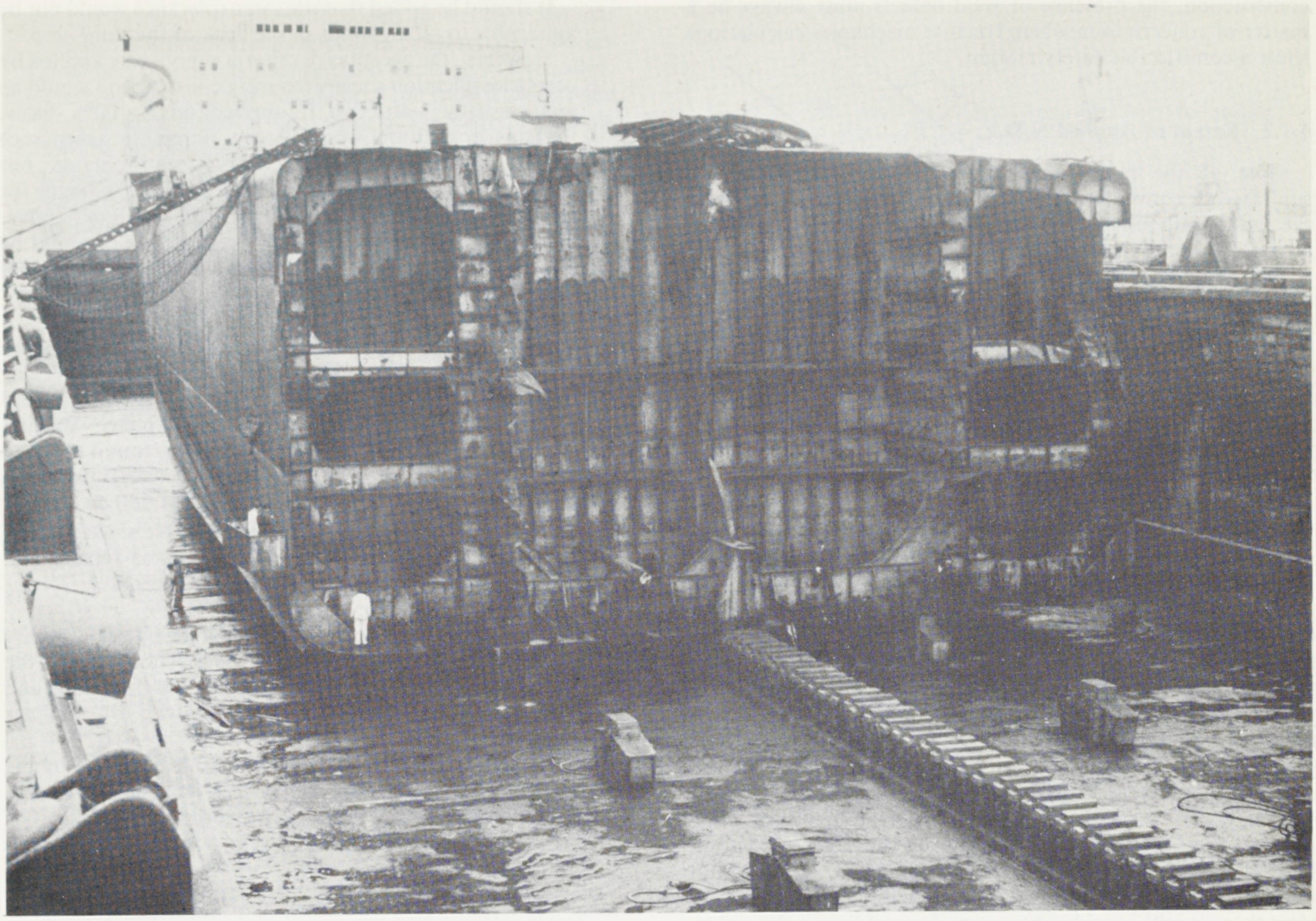


Fig. 7

Casualty resulting from brittle fracture in M.T. *Kurdistan*

Similarly, the defect visible in Fig. 9 occurred in another weld not considered worthy of N.D.E. This 'weld' was one of a series of erection butts in the flange sections of the side longitudinals in a 250,000 ton VLCC. These defects eventually propagated by fatigue across the web plates of the stiffeners to the attachment of the longitudinal to the side shell. At this critical stage the ballasted tanker met rough weather and a crack propagated by brittle fracture. The crack propagation was briefly arrested at the Grade EH steel of the gunwale before propagating via a seam weld and a butt into a deck strake where it was finally arrested.

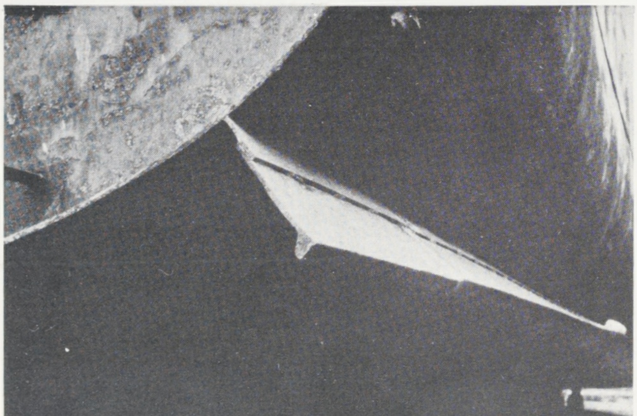


Fig. 8

M.T. *Kurdistan*—Bilge keel plate arrangement

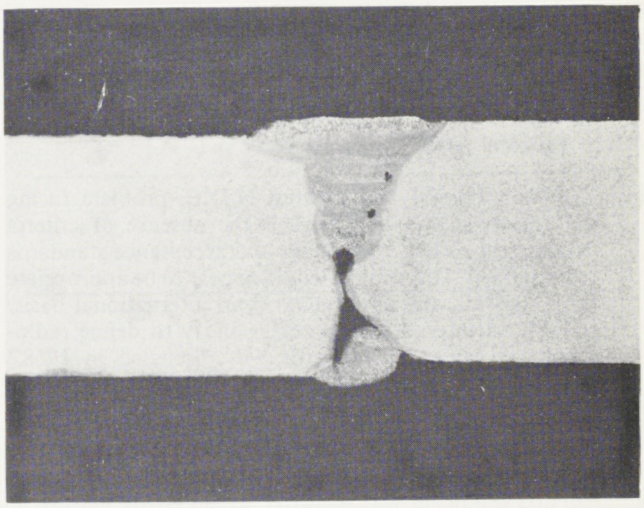


Fig. 9

Defective butt weld in side longitudinal flange

It should always be remembered that a weld defect innocuous under normal operating conditions can initiate fast fracture under abnormal conditions of applied stress, particularly at low temperatures. As shown above it is possible for defects to grow by fatigue until they reach a size capable of initiating fast fracture.

In view of the trend towards thinner sections used in ship

construction, the presence of weld defects must always be a matter of concern even where fracture mechanics calculations show a comfortable safety margin.

4.1.2 Extent of Applied N.D.E.

Most of the major components in the machinery are subjected to conventional N.D.E. during manufacture. From the limited amount of in-service N.D.E. applied it must be assumed that the machinery comfortably outlasts the hull.

The amount of N.D.E. applied during hull construction expressed as a percentage of total weld length, is not so extensive. Some classification societies base the required number of checkpoints upon the formula;

$$n = L\frac{(B+D)}{46.5} \quad \text{where} \quad \begin{aligned} L &= \text{length of ship} \\ B &= \text{moulded breadth} \\ D &= \text{moulded depth} \end{aligned}$$

For a 400,000 ton crude carrier this represents 800 checkpoints, or approximately 1% of the length of seams and butt welds within the 0.4 L section.

Many shipyards would take an additional number of radiographs bringing the number to about 1500 for a vessel of this size.

Supplementary ultrasonic examinations will be made by most shipyards with additional magnetic particle inspections of fillet welds at stiffener connections.

Since the examinations are made at the points of highest stress such as weld cross-junctions in bilge strakes, shear strakes, deck stringers and keel plates, or in the vicinity of hatch covers and at representative erection berth butt welds within 0.4L amidships, the coverage is more significant than it would appear at first sight. However, from a quality control point of view there is still considerable scope for welding malpractice.

The Society's Rules for liquefied gas carriers are naturally more stringent. It is a requirement that all primary barrier welds are examined by radiography.

The shipbuilder may apply to the Society for consent to use ultrasonic testing in lieu of radiography with a percentage of radiographic checks being retained. Strict attention must be paid to the proficiency of any ultrasonic personnel employed on shipyard work.

4.1.3 Problem Areas

(a) **Criteria.** Possibly the greatest N.D.E. problem facing the Society's Ship Surveyors is the absence of criteria defining the extent, techniques and acceptance standards to be applied. This subject would appear to be appropriate for discussion and agreement on an international basis. Indeed, an international working party to define radiographic acceptance standards was discussed in 1968.[9] Other major classification societies have since published their own criteria, often indistinguishable, and the Society's Surveyors are becoming increasingly isolated in this area.

Satisfactory techniques for radiographic, ultrasonic, magnetic and penetrant testing methods are available and the extent of testing could be defined after assessing current practice. It may be that simply applying the formula $n = \frac{L(B+D)}{20}$ would provide the right number of radiographic checkpoints. The stumbling block would appear to be the question of acceptance standards. Criteria based on fitness for purpose requirements could be over tolerant if applied during construction. For example a tolerable defect size for a flaw in the central zone of a deck butt weld, 30 mm thick, has been estimated at 6 mm height.

It should be added that the same tolerance would not be applicable to all locations in the deck of the same ship.

However, the acceptance criteria supposedly applied by other classification society's during construction would be unnecessarily restrictive if applied on a 100% basis. Perhaps a solution would be to nominate acceptance criteria based on quality control requirements but applicable only to those areas selected by the Surveyor for inspection in accordance with the extent defined above. Repair rates of above, say 5%, in these areas would be cause for increasing the extent of quality control inspection.

(b) **Weld Quality.** The most common faults in shipyard welding are porosity, incomplete penetration and slag inclusions. In some ships examined by the author weld penetration has been distinctly incomplete. Welders appear to be reluctant to back-gouge into sound metal so that a fully penetrated weld can be made. Also, there is a reluctance in some yards to remove weld defects to their full extent. A walk along the decks of these ships with an ultrasonic set testing the areas adjacent to repairs will reveal the continuations of the original defect.

(c) **Material Quality.** The problems caused by poor quality steel include lamellar tearing at connections where the plate is stressed in the through thickness direction, and laminations at butt welds and in way of stiffener connections.

The problem of lamellar tearing is best avoided by the use of Z quality steel which has enhanced through thickness properties. The weld section shown in Fig. 10 is an example of lamellar tearing at a tank top-bulkhead junction.

Repeated attempts at repair merely pushed the lamellar tearing deeper into the parent plate. The ship in question was eventually repaired, not without mishap, by the insertion of bar material at all tank top-bulkhead junctions.

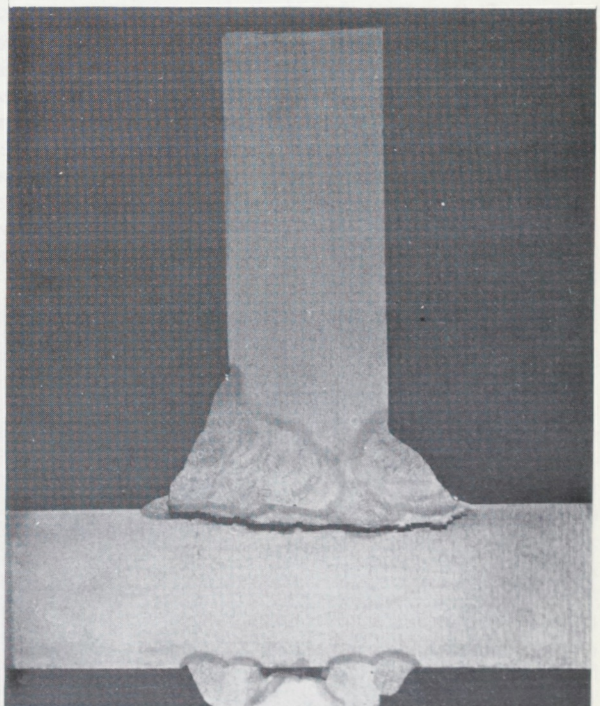


FIG. 10
Lamellar tearing at tank top-bulkhead junction

The problem of laminations and particularly laminar inclusions is one that may appear in concast (continuously cast) steel plate when the process is improperly controlled. The microstructure of this material can show a heavy band of inclusions either at the centre of the plate or midway toward one surface depending upon the manufacturing process used. Where the inclusions are toward the plate surface adjacent to a tee butt weld the tendency is for individual inclusions to open up (decohere) during welding. When this happens the inclusions are detectable by ultrasonic testing. Complete de-laminations should be detected ultrasonically by inspection at the plate mill. Small laminations are of no consequence unless they occur in-way of welded connections. The question of acceptance criteria for the ultrasonic testing of ships' plate is another topic which could usefully be pursued by the Society.

(d) **Falsification** Unfortunately for the Surveyors any competent radiographer who sets out to deceive is liable to succeed. It would be naive to pretend that the number of discovered cases of falsification represented the bulk of this particular iceberg.

At one end of the spectrum of falsification is the lazy radiographer who prefers to fake a series of radiographs at one easily accessible location. At the other extreme is the yard that fitted machined bars into weld preparations, covering the bars with a capping run to reduce welding time and costs. Unscrupulous yards have also been known to take an entire series of radiographs on welded plates completely unrelated to the structure under survey.

The most common malpractice by individual welders is the insertion of electrodes at weld roots. In some cases the insertion may assist welding due to the fit-up at that location, more often it is simply a dishonest short cut easily detectable by N.D.E.

More difficult to detect is the practice of repairing areas shown to be defective by radiography without advising the Surveyor. Repair radiographs are then submitted to the Surveyor as being original radiographs. In these cases the original defect is highly unlikely to have been removed to its full extent. Any Surveyor seeing significant numbers of half-metre repairs at supposedly clear weld junctions should call for and witness ultrasonic tests in the immediate vicinity.

4.2 Offshore

4.2.1 The development of the offshore oil and gas fields during the 1970's has had a tremendous impact on the N.D.E. industry in Europe creating a big demand for the equipment and personnel. Offshore related N.D.E. is now one of the biggest sectors in the market.

In addition to the routine assessment of procedures and personnel for offshore projects N.D.E. Surveyors have audited the testing applied at all sites involved on the B.P. Magnus Project and have supervised the re-fitting of two Pentagone type semi-submersibles.

The extent of N.D.E. applied during the construction of an offshore installation follows the same pattern for most installations. All full penetration welds in the primary structure are examined by radiography or ultrasonics according to thickness and configuration with supplementary magnetic particle inspections. A percentage of secondary structure welds will also be examined by these methods. The full extent of applied N.D.E. is described in the Survey Procedures Manual, Part J. 6.2 (e).

Many of the N.D.E. limitations previously mentioned apply equally to offshore applications however the following points are of particular relevance.

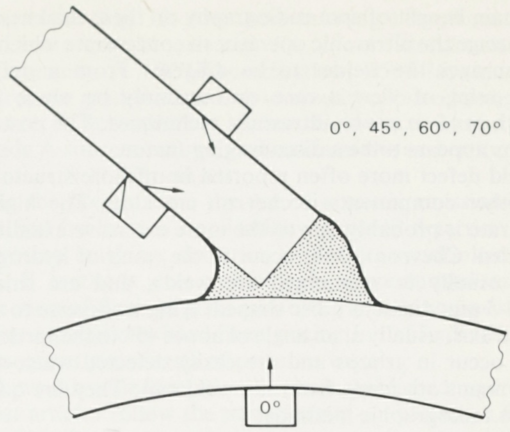


FIG. 11

Ultrasonic examination of node welds

4.2.2 Node Welds

Node welds at the junctions of tubular members present special problems due to their configuration. Ideally, node welds should be examined from both inner and outer surfaces by magnetic particle and ultrasonic testing with additional ultrasonic testing from inside the continuous tubular member, (Fig. 11). When access is restricted by diameter, length of stub, internal stiffeners or spacer plates the efficiency of the examination will be reduced. Single sided ultrasonic or magnetic examinations of the crotch areas of some K or Y connections (Fig. 12) are so restricted by the weld root configuration that it may be prudent to build up these areas by welding as a matter of routine.

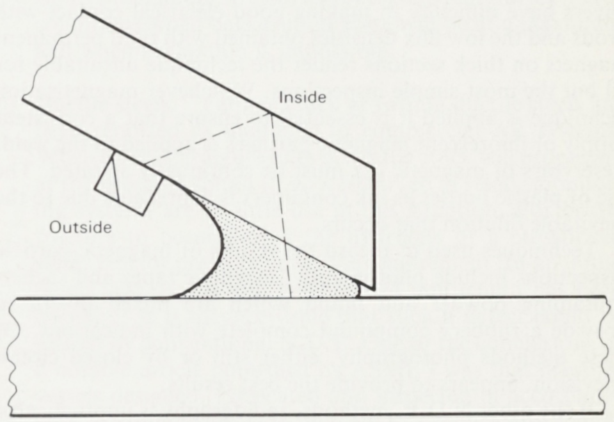


FIG. 12

Limitations imposed by restricted scanning access

The best external magnetic technique for these areas is the encircling coil method using parallel conductors, always provided that the junctions are not complicated by the presence of stiffener gusset plates. However, the encircling coil method is seldom applied presumably because the remaining 80% of the weld is more easily inspected by conventional methods. If the encircling coil method is not applicable then the current flow method using prods is preferable to the fixed yoke method provided that any contact burn marks are removed by grinding.

4.2.3 Butt Welds

Many butt welds are made in tubular members having thicknesses above 75 mm. The limitations of N.D.E. on thick welds have been discussed in 2.1.4 and 2.2.4. A cynic would say

that the main benefit of spot radiography on these thicknesses is to encourage the ultrasonic operator to concentrate which in turn encourages the welder to be diligent. From a defect detection point of view a case can certainly be made for automated, tandem probe ultrasonic techniques. The cost of the systems appears to be a discouraging factor.

One weld defect more often reported in offshore structures than in other components is chevron cracking. The higher detection rate is probably due to the more extensive examinations applied. Chevron cracks occur as the result of hydrogen cracking, usually in submerged arc welds, and are small, typically 3-5 mm diameter, disc shaped, lying transverse to the major weld axis, usually at an angle of about 45° to the vertical. Chevrons occur in groups and are easily detected when 45° ultrasonic scans are made from the weld cap. They are quite invisible to radiographic methods.

4.2.4 Underwater Examination

In-service underwater examinations generally consist of visual inspection, ultrasonic thickness determination of risers and platform structure, cathodic potential monitoring and occasional magnetic particle or electromagnetic examination of welds. The N.D.E. techniques applied are also described in the Survey Procedures Manual, Section 8, Part J. The locations for underwater examinations are usually determined by analysis and identification of highly stressed areas, by previous experience or by accidental damage.

Examination methods applied underwater are essentially waterproofed version of those used above water. Magnetic particle inspection using water based fluorescent magnetic ink and ultra-violet illumination is the most widely applied method for weld examination. The technique to be encouraged is the encircling coil method whereby a cable carrying about 1000 amps a.c. is placed adjacent to the weld providing the magnetisation. This technique is quicker and more efficient than either the prod method or the magnetic yoke method. Divers have difficulty in making good electrical contact with prods and the low flux densities obtained with rigid permanent magnets on thick sections render the technique unsuitable for all but the most simple inspections. Whichever magnetisation technique is applied it is essential to ensure that a consistent supply of fluorescent magnetic particles is applied to the weld. Reservoirs of magnetic ink must be continually agitated. The use of plastic bottles as ink containers is deprecated due to the inevitable dilution that occurs.

Techniques used to record the results of magnetic particle inspections include photography, magnetic tapes and sachets containing powder and liquid which are mixed in-situ to provide a rubbery compound complete with indications. Of these methods photography, either still or by closed circuit television, appears to provide the best results.

Of the other N.D.E. methods, radiography is impracticable for most applications except for habitat working or for corrosion assessment in smaller diameter risers. Ultrasonic weld testing is so slow underwater that it cannot be applied as a primary test method. Even when used for defect evaluation purposes the value of the method is questionable. The application of ultrasonic torches, (devices held near to a component), for defect detection has also met with little commercial success.

An electro-magnetic method has been developed for weld inspection underwater and has been applied with some sucess. A slight disadvantage of the system is that the inspections are directed and controlled from the surface relying on co-ordination between controller and diver. Advantages of the system are that scanning rates are comparatively rapid, 4 m/hr has been quoted, and that the equipment carried by the diver is much more portable than the magnetic equipment.

At the current state of the art the best underwater weld inspection method is considered to be the encircling coil magnetic method.

4.3 Industrial Services

4.3.1 Most of the aspects of N.D.E. pertinent to Industrial Services work have been discussed in other sections of this paper. Problems posed by pressure vessel N.D.E. are interesting but not usually unique to Industrial Services. One subject that is unique is that of nuclear related N.D.E. The N.D.E. Surveyors are involved in the auditing of the annual shut-down inspections of the Magnox reactors at Calder Hall and Chapel Cross and also in the inspection of the Steam Generating Heavy Water Reactor at Winfrith. Procedures and applied testing for the Advanced Gas-cooled Reactor under construction at Heysham are also assessed. One problem of particular interest to nuclear related N.D.E. is the testing of coarse grained welds in stainless steel, which is discussed below.

4.3.2 Stainless Steel Welds

These welds range in size from the 3 mm thick, 25 mm O.D. tubes for the A.G.R. boilers up to primary loops connecting the reactor pressure vessel to the heat exchangers in Pressurised Water Reactors. All of the welds must be examined.

Radiographic techniques are applied to the 36 mm diameter, 5 mm thick transition butts for the A.G.R. superheater tubes using panoramic techniques with either Thulium 170 gamma ray sources or 150 kV panoramic microfocus rod anode X-ray sets. The gamma ray source has an approximate equivalent energy of only 100 kV, unfortunately the source size of 0.5 mm is slightly too large for the application and as a result produces radiographs of relatively poor definition. The 150 kV X-ray set has a focal spot size of less than 0.1 mm. The resulting radiographs are of excellent quality although diffraction can cause some spurious indications. An ultrasonic examination of the 3 mm thick stainless steel butt welds is made using 8 MHz probes mounted in suitable probe holders. This examination is essentially a go-no-go system.

The butt welds in the primary loops of P.W.R.'s have received a great deal of attention due to the potentially catastrophic consequences of a failure. Problems with the location and sizing of defects found by ultrasonics are caused by beam skewing and velocity variation across the weld.

Research has shown that 45° longitudinal wave probes cope best with the columnar structure of these welds. Computer techniques have been applied to differentiate between crack signals and spurious noise from the grain structure. The Americans claim to be on the verge of installing ultrasonic systems capable of detecting and monitoring intergranular stress corrosion cracks in primary loop welds.

Sub-cladding cracks have occurred in several European P.W.R.'s at nozzle radii and in tube plates.[10] The cracks appear in the base metal heat affected zone of the second layer of cladding and are believed to be caused by the cold cracking phenomenon. The problem is reported to be associated with the presence of hydrogen and requires high residual stresses and susceptible material for propagation. The cracks are typically 1-12 mm in height, between 10-50 mm in length, occurring in clusters.

Detection and monitoring of the defects is done with focussed, twin crystal, 70° longitudinal wave probes. Defects are detectable at a size of 1 mm height compared to a critical defect height of 30 mm. Fatigue analysis has shown that these defects are unlikely to reach critical size during the 40 year life of the reactor.

5. RECENT DEVELOPMENTS

Anyone preparing this paper in 1972 would probably have described acoustic emission testing, automated ultrasonic testing and eddy current testing as being recent developments likely to find widespread application in the immediate future. This may still be true in 1982. In the absence of any dramatic developments in N.D.E. the progress in these three methods is discussed below.

5.1 **Acoustic Emission Testing**

Acoustic emission has been defined as the high frequency waves generated by the rapid release of strain energy that occur within a material during crack growth, plastic deformation or phase transformation. Transient acoustic emission waves may be detected by piezoelectric sensors attached at selected locations on a structure. The most simple form of analysis will display the number of events occurring in a given time. This system would be used for zonal location of defects in, for example, a glass reinforced plastic vessel. More complex analysis using computers can identify with some accuracy the locations and activities of the emission sources. Signal processing can also be used to discriminate between background noises and significant events.

In metals the initiation and growth of cracks are prime sources of acoustic emission. For this reason viable AE techniques would represent an attractive method of monitoring structures such as reactor pressure vessels and offshore installations where failure could have catastrophic consequences.

Before AE can be applied it is necessary to consider factors such as material characteristics, geometry and operating conditions that will determine the number of sensors required. For example, a pressure vessel such as a 20 metre tall hydrocracker could be monitored with 12 transducers, whereas a complex node in an offshore platform could require twice this number.

Acoustic emission can be applied whilst plant is in operation. By using waveguides it is possible to monitor pressure vessels in service at temperatures of up to 400°C. In most cases, however, it will be necessary to shut down the plant to reduce background noise to an acceptable level.

In theory AE has the advantage that only those defects which are active will emit. In practice the signals from growing defects must be identified against the background noise emanating from such diverse sources as machinery operating in the vicinity, fluid flow within the system, and external events such as wind, rain or waves. Spurious noises from external sources can be intercepted and identified by the use of guard transducers placed at the boundary of area of direct interest. In addition the use of a coincident detection system can be used to identify emissions from areas of interest whilst simultaneously rejecting any other emissions. When random noise originates within the area of interest micro-processors can be programmed to apply pattern recognition techniques to classify all indications on the basis of signal rise time, decay time, amplitude, event duration and frequency peak.

Events giving acoustic emission can be displayed in real time on a storage oscilloscope, superimposed on a schematic of the

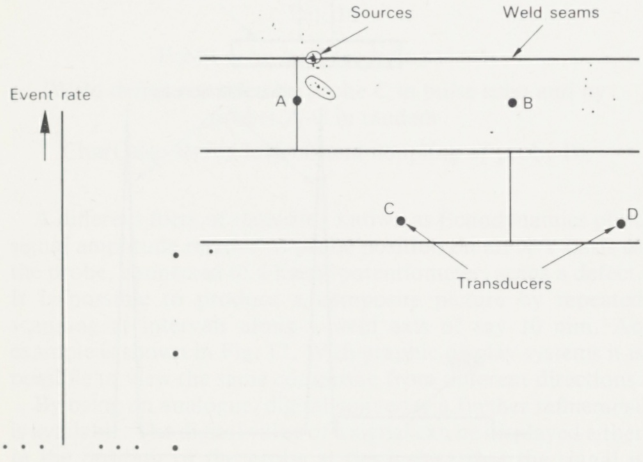


FIG. 13

CRT display of events received from Acoustic Emission

component, Fig. 13. Any areas showing a significant build-up of events can be selected for closer assessment. It is a requirement of ASTM specification, E569-76, that emission sources be graded according to severity. Sources are graded A, intense; B, active but not intense; C, low activity and intensity. Grade A sources require evaluation at the earliest opportunity by other N.D.E. methods.

At the present time the use of acoustic emission has been justified for certain applications, notably detection of stress corrosion cracking, detection of defects overlooked by other N.D.E. methods, detection of leaks in pressurised systems and detection of flaws in glass reinforced plastic components. The main applications have been during initial hydrotests and at subsequent proof tests of pressure vessels.

A wealth of information has been published regarding AE. Most articles follow the same format—a glossary of terms, a detailed description of the system and a few lines about whatever was detected. It has been difficult for the N.D.E. Surveyors to make a full appraisal of the system since many plant operators are reluctant to invite inspection authorities to witness tests, presumably because of the large number of spurious indications presented. The following comments regarding the limitations of the system are made from a review of available literature.

5.1.1 **Limitations**

(a) **Kaiser effect.** Most defects only propagate whilst the applied stress equals any previously applied stress. For an offshore installation this poses a severe problem since previous maximum stresses are probably unknown and because platform operators are reluctant to apply unnecessary stress. One operator in the Gulf of Mexico did apply an overstress in the form of a tug repeatedly ramming the installation. In more conventional circumstances maximum stresses are likely to occur during storm conditions when background noise will be at a maximum and when evaluation is impossible.

(b) **Ductile steels.** Fatigue crack growth in ductile steels has been reported as inaudible to commercial AE systems. When a brittle fracture does occur the crack will propagate at the speed of sound (5.92×10^3m/sec in steel), monitoring systems are of little use in this situation. For brittle fracture to occur during the hydrotest of a pressurised water reactor pressure vessel the requirement for an initial defect size of 104 mm height $\times$ 624 mm length has been quoted.[11] It is inconceivable that such a defect could be missed by conventional N.D.E. One of the conclusions of a notable article published by ASME[12] was that pressure vessels designed, fabricated and inspected in accordance with existing codes were unlikely to produce any significant emission during hydrotest.

(c) **Evaluation.** The grading of emission sources is not yet reliable. Many Grade A sources are found on evaluation to be from insignificant events such as the decohesion of Manganese Sulphide or non-metallic inclusions. Emission sources have to be evaluated by conventional N.D.E. methods which may be inapplicable due to lack of access. In an offshore platform the small weld discontinuities acceptable to construction criteria are potential sources of acoustic emission. Each one would require detailed evaluation, a procedure beyond the scope of modern technology.

(d) **Cost.** To buy a comprehensive AE system would cost over £600,000. To hire a system to make one assessment of a typical pressure vessel would cost £2000-£3000 for a two day period. Costs increase with the number of transducers therefore it would be too expensive to inspect an offshore platform on a total basis.

5.1.2 **Summary**

At present AE is a proven technique for the detection of stress corrosion cracking in pressure vessels. It is of limited value for nuclear reactors and offshore installations due to (a) low noise level of fatigue crack growth in the steels used, (b) insufficiently quantitative nature of information obtained and (c) difficulty of access for evaluation of sources. These difficulties exist whether the sensors are attached to the structure or whether they are suspended in water at a distance from the structure as in a recent Swedish development. However, progress in the data processing side of AE is so rapid that the method must still be regarded as a possible system for the future.

5.2 **Eddy Current Testing**

There are many techniques within the eddy current or electro-magnetic method. Essentially the method consists of placing a coil carrying alternating current in proximity to the surface of a component. Eddy currents are induced in the component. Any change in the characteristics of the material will affect the eddy currents. These changes are detected by observing changes in the impedance of a search coil.

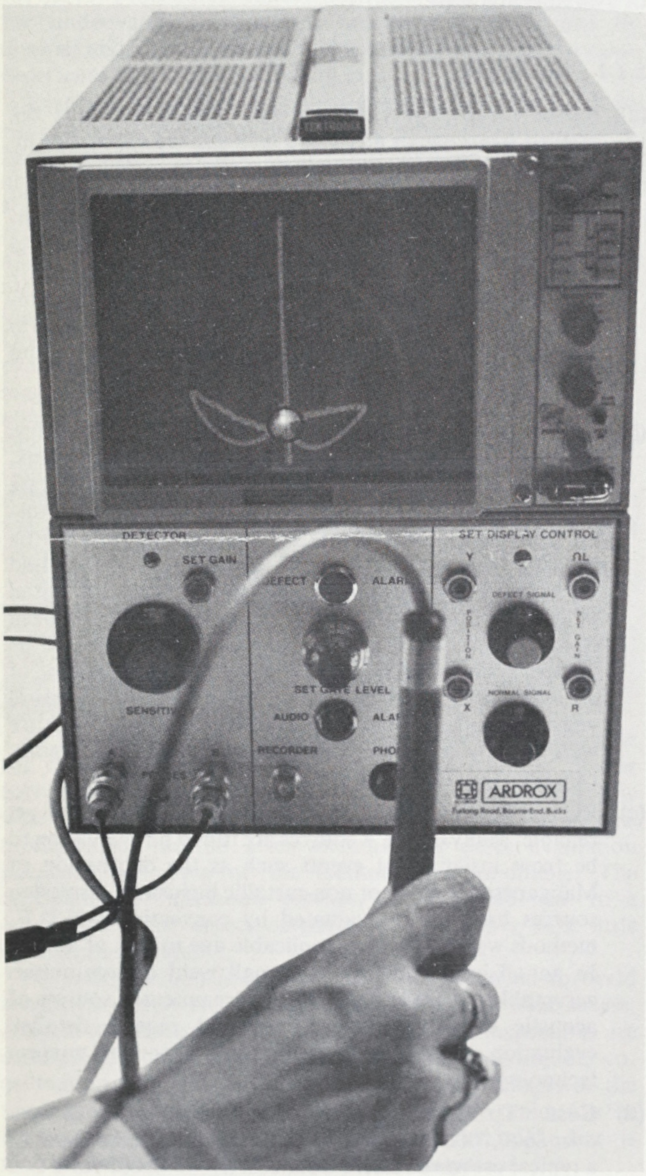


Fig. 14

Electro-magnetic system for crack detection

One system for testing wires, rods or tubes uses an encircling search coil with two encircling secondary coils. Any change in the characteristics of the material in the vicinity of one of the secondary coils creates an imbalance which is used to trigger a marking or warning system.

Other systems use probes of various shapes to scan the surface of the component.

Factors that can be detected by eddy current method include defects and changes in thickness, conductivity, microstructure and coating thickness.

Developments in the eddy current method have resulted from the use of storage oscilloscopes to display the results of the tests. Older instruments used a meter to indicate changes in material characteristics without identification of the exact nature of the change. Storage oscilloscopes can display impedance changes as an X-Y display known as the impedance plane curve, the X axis representing the resistive component, the Y axis representing the reactance. With a storage oscilloscope it is possible to identify the nature of the change in the component. In one of the more recently developed electro-magnetic systems cracks are shown by an impedance plane curve in the vertical 0° direction. Fig. 14. This system is able to detect cracks in ferritic welds without extensive surface preparation. The search probe can be used underwater to a depth of 400 m and has been applied to the welds of offshore installations.

The electro-magnetic method possibly has a greater 'potential' for development than any of the other N.D.E. methods.

5.3 **Automated Ultrasonic Testing**

Automated ultrasonic testing is by no means an innovation. It has long been recognised that the tedium of scanning large areas by hand can lead to mistakes. Automated testing of plates, tubes and welded pipes has been applied for some years. However the goal of the designers, a simple automated system applicable to all weld configurations has yet to be realised.

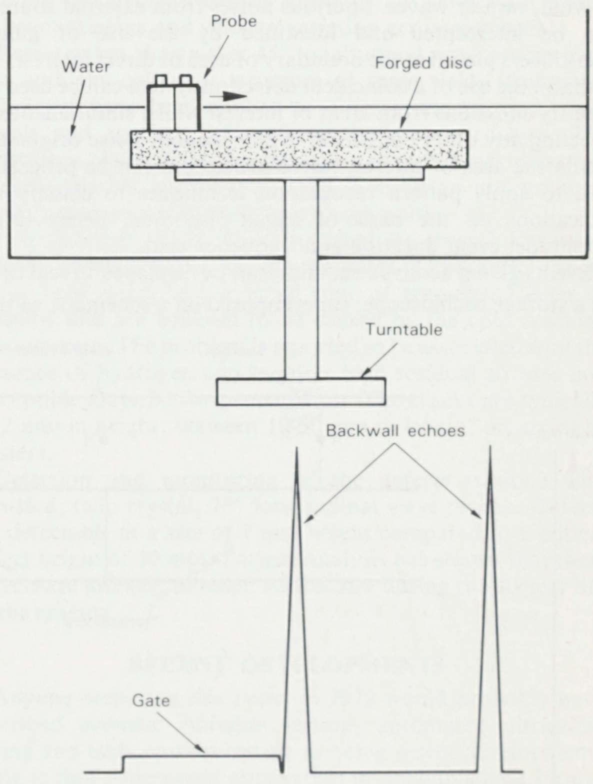


Fig. 15

Automated immersion testing of disc forging

A comparatively simple system used for the examination of forged turbine discs is shown in Fig. 15. Systems of this type utilise water immersion tanks to obtain uniform acoustic coupling; the forgings being rotated on a turntable as the probe traverses diametrically. A modification to this system has a stationary component with a probe traversing on an X-Y grid. The probe movement is linked to an X-Y plotter giving a plan-position indication of any forging defects.

The key to all automated systems is the 'gate' shown superimposed on the time base of the ultrasonic display, Fig. 15. Signals appearing within this gate and exceeding a selected amplitude are used to trigger a marking or recording device. The width and position of the gate are adjusted to suit the dimensions of the component.

When a component such as a weld is examined by more than one probe the recording equipment becomes more sophisticated. Each probe will have its own gate on the timebase coupled to a separate recording channel. This means that probes must be switched sequentially at high speed to ensure full coverage. For a fraction of a second whilst a particular probe is operating, the gated timebase calibrated for that probe is displayed and signals occurring within that gate are fed to the recording channel for that probe. Each probe in an array operates in sequence. A six probe array and eight channel recording chart is shown in Fig. 16.

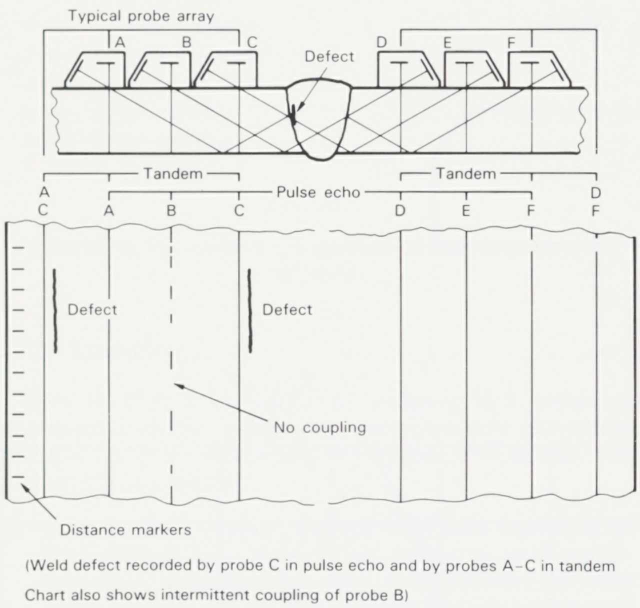


Fig. 16

Probe array and recording chart

(Weld defect recorded by probe C in pulse echo and by probes A-C in tandem

Chart also shows intermittent coupling of probe B)

A different form of recording known as Echodynamics plots signal amplitude relative to probe position on an X-Y basis as the probe, connected to a linear potentiometer, scans a defect. It is possible to produce a composite picture by repeated scanning at intervals along a weld axis of say 10 mm. An example is shown in Fig. 17. With graphic display systems it is possible to view the same composite from different directions.

By using an analogue/digital converter a further refinement is available. The digital value of a signal can be displayed either in the position of the probe at the instant that the signal is obtained or on a cross-section of the component at the position of the defect. An example of this recording system is shown in

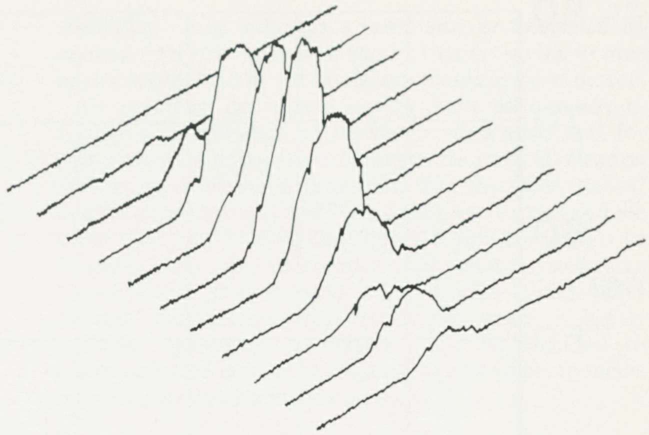


Fig. 17

Echodynamics recording of ultrasonic test

Fig. 18 *(overleaf)*. In practice, the printed display will be colour-coded to show the relative amplitudes of the signals, usually on a 6 dB contour line basis.

A still further refinement of recording systems is the facility to store data and to select a desired sensitivity level for display. A weld can be scanned and the results displayed at low or high sensitivity as required. By programming the display it is possible to show the results at 20%, 50% or 100% of a reference level such as that provided by the ASME Code. The projection-scan system developed by the Danish Welding Institute has this facility and displays the results as a plan view and also as a vertical longitudinal section of a weld. Fig. 19. This system uses individual probes, therefore several recordings will be made for a given weld section.

The probe arrays used to obtain data for these recording systems come in an ever increasing variety. The simplest weld testing system will use probes at a fixed distance from a weld axis relying on beam spread to cover the entire weld volume.

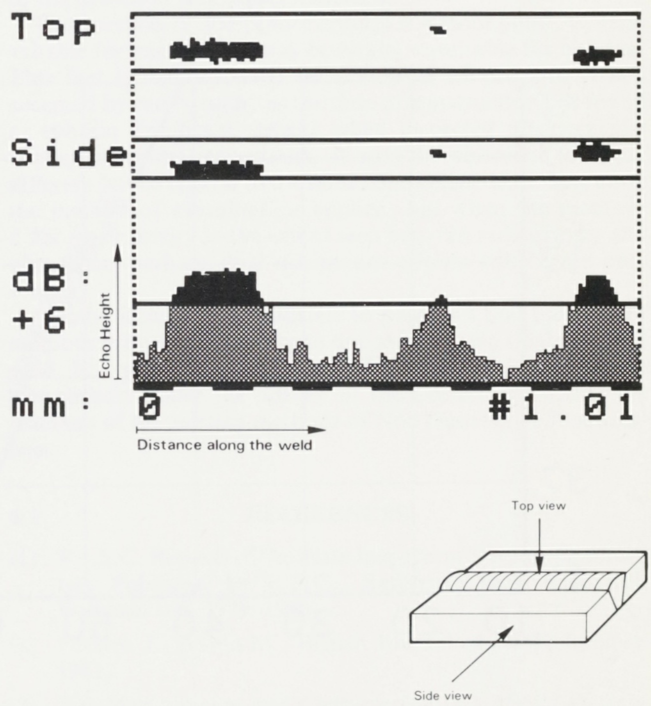


Fig. 19

Projection scan results

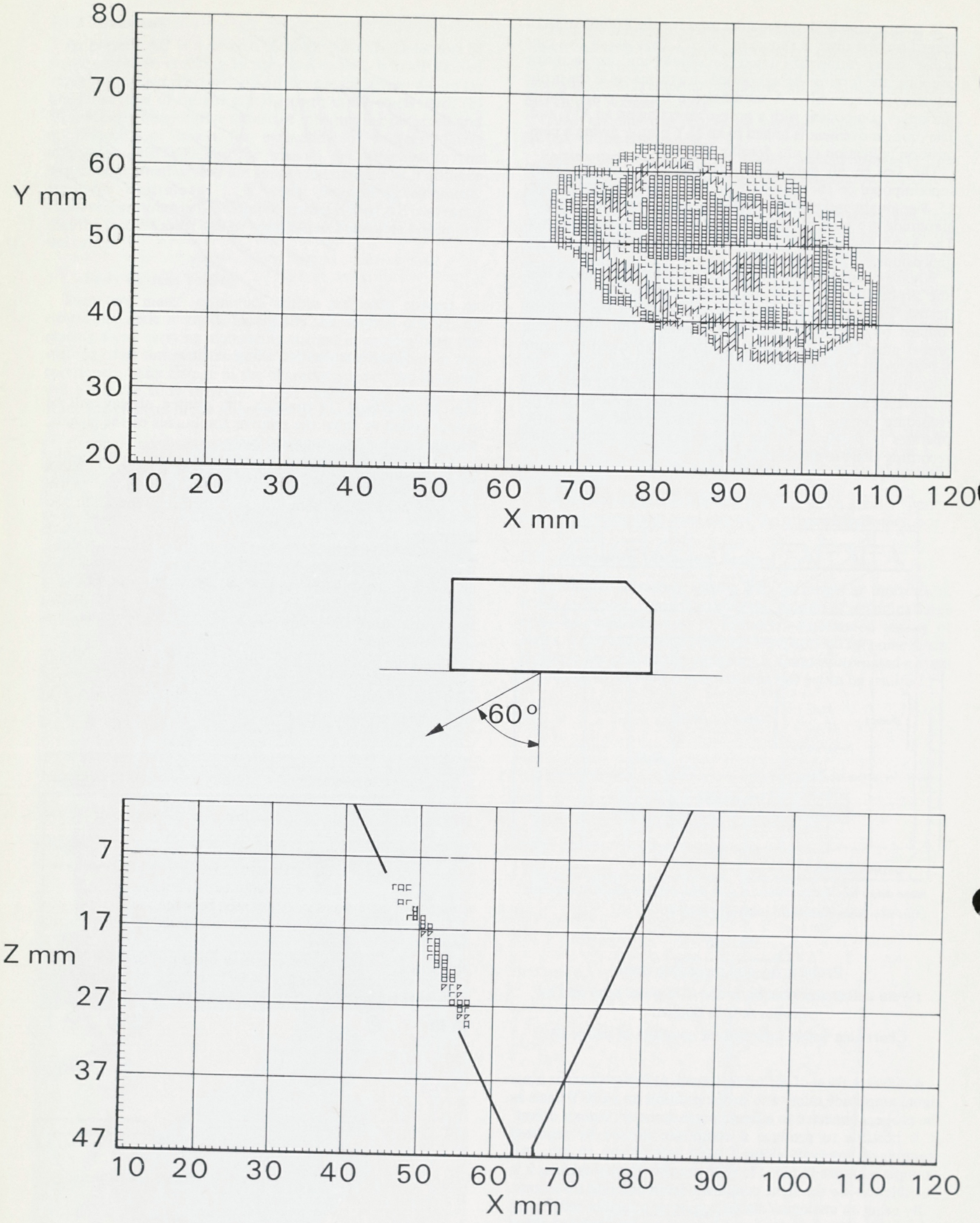


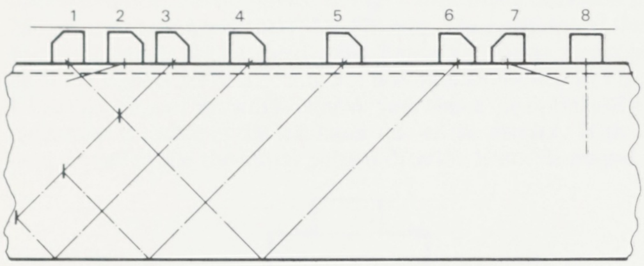
FIG. 18

Digital recordings of defect shown as
(a) C-scan (or plan position indication) (b) XZ projection

This system has the disadvantage that signals from those defects on the beam axes will have greater amplitudes than signals from other defects of the same size scanned by the beam edge. This type of probe array will be pushed along the weld seam or it may be rotated around a circumferential weld using a cogged belt.

To eliminate the problem posed by variations in intensity across the ultrasonic beams the probe array can be oscillated so that the beam axes scan the entire weld volume.

On thick welds such as those used in reactor pressure vessels arrays of probes operating singly and in tandem will be used, Fig. 20. Scans will be made from both sides of the weld.



1 ► 1 IE technique: Impulse Echo technique

1 ► 6 Through transmission

2 ► 2 LSE: Longitudinal wave techniques twin crystal probes

3 ► 6 Tandem technique

3 ► 5 Tandem technique

3 ► 4 Tandem technique

6 ► 6 IE technique

7 ► 7 LSE technique

8 ► 8 IE technique

FIG. 20

Probe array for in-service inspection of reactor pressure vessel welds

5.3.1 Limitations

With the apparent wealth of scanning and recording equipment available it may seem surprising that automated testing is not more widely used for routine weld testing. The problems are as follows:

(a) **Weld Profile.** Signals received from weld caps must be distinguished from possible toe cracks or root cracks. Because of beam divergence the corner reflector provided by the weld cap and the sites of possible cracks are scanned simultaneously. These reflectors would be distinguished manually by slight differences in range from the probe.

If an automatic system is to be 'gated' to resolve these reflectors the weld configuration, thickness and alignment and the distance between the probe and the weld centreline must be absolutely constant. This condition has proved to be unattainable in shipyards and on offshore construction sites. If weld profiles are 'gated out' a considerable volume of weld metal is also omitted. For plate welds in ships this can result in only the least important zone of the weld volume being examined, the more important surface areas would be gated out with the weld caps. One of the better systems the R.T.D. Bandscan, tackles this problem when testing pipeline girth welds by utilising the guide rails installed for the actual welding process.

(b) **Extent of Scanning.** Ultrasonic procedures for weld inspection require 0° scans for plate laminations and scans for transverse weld defects in addition to the obvious scan for longitudinal weld defects. These additional scans complicate the 'simple' system and are sometimes applied manually. Since indications must also be evaluated by manual operators the result can be that no saving in time or cost is obtained by the use of automated systems on site.

In summary, automated systems have definite advantages for components of regular configuration and for components in hostile environments. On most fabrication sites manual testing is preferred. The fact that manual operators sometimes omit 0° and transverse scans and are often confused by weld cap signals is immaterial. To be formally acceptable an automated ultrasonic system, like Caesar's wife, must be seen to be innocent. Unless more tolerant specifications are introduced, which is highly unlikely, automated ultrasonics will be confined to components of regular configuration and to components operating in hostile environments.

6. CONCLUSIONS

In the preceding sections the theoretical and practical aspects of N.D.E. relevant to the Society have been reviewed. Whilst each Surveyor will draw his own conclusions regarding the value of N.D.E. the following general conclusions are stated:

(a) Correctly applied N.D.E. methods will find defects in components that might otherwise have been accepted.

(b) The application of N.D.E. does not guarantee that a component will be free from defects. Optimum results will only be obtained with thorough surface preparation and by the application of the most suitable method using trained personnel with adequate equipment.

(c) Precise identification of defect nature and exact measurement of defect extent will not always be possible. Fracture mechanics calculations and acceptance criteria should acknowledge the limitations of the N.D.E. methods.

These conclusions may appear to be a slight indictment of N.D.E. In fact they are a reflection of the gradual progress that has occurred since the first pressure vessels were X-rayed over fifty years ago. As technolgy improves not only does defect detectability improve but also our knowledge of the limitations of the detection techniques increases.

The question of acceptance criteria is a moot point. Criteria suitable for one method may be totally unsuitable for another. This fact is demonstrated by a number of pressure vessels accepted by radiography at the time of construction but found to contain significant defects when inspected ultrasonically during in-service inspections. It may be abhorent to apply different sets of criteria to the same component depending upon the method of examination applied, but when the methods differ in sensitivity to the extent seen between radiography and ultrasonics perhaps dual acceptance criteria will be the only answer.

Finally, it may be appropriate to point out that the N.D.E. methods are complementary to one another. No single method need be applied in isolation. The great majority of the components under the Survey of the Society are within the compass of the existing methods of Non Destructive Examination.

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APPENDIX I

CALIBRATION OF FLAW DETECTORS

1. RANGE

Range is the distance between the probe and the reflector, i.e. half the actual path length travelled by the sound wave.

1.1 0° Probes

1.1.1 To calibrate range for a 0° probe, the probe is placed on one surface of a parallel sided block so that two or more backwall echoes are displayed. In Fig. I.1 the block thickness is 25 mm and the range displayed is 100 mm. The positions of the backwall signals are adjusted using Range and Delay controls until the signals are at 2.5, 5.0, 7.5 and 10.0 as shown. In Fig. I.1 the probe is of the single crystal type, hence the initial pulse indication is visible at the left hand side of the display. With a twin crystal probe the initial pulse indication is not displayed.

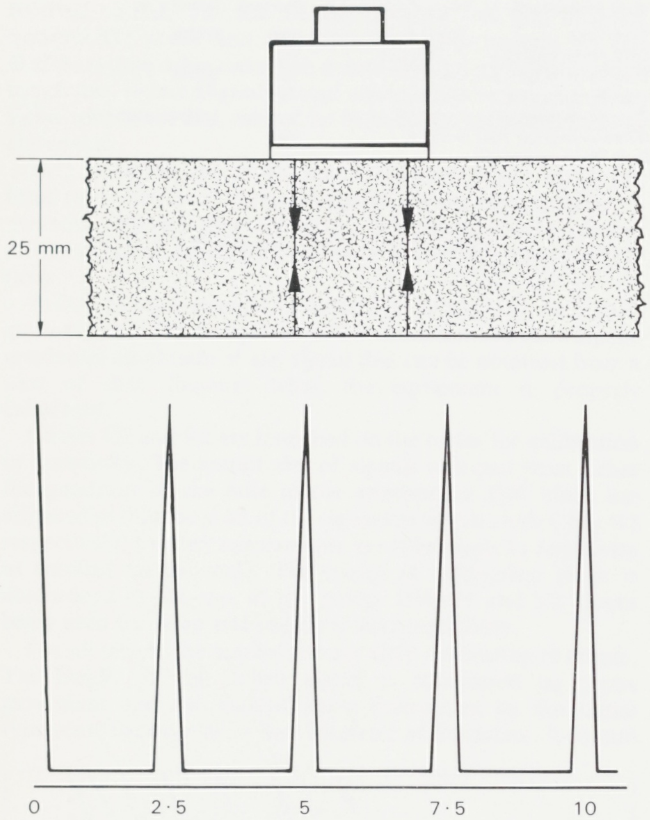


FIG. I.1

0° probe Calibration, 100 mm

1.2 Angle Probes

1.2.1 Angle probes are placed at the centre of a radius of curvature as shown in Fig. I.2. The IIW V1 block shown in Fig. I.2 has a radius of 100 mm with reflecting notches at the centre so that repeat signals are obtained.

The range calibration shown in Fig. I.2.2 is for 200 mm.

1.2.2 The IIW V2 block has radii of 25 mm and 50 mm but has no reflecting notches so that a sound wave aimed at one radius will reflect back to the probe giving a signal and will then travel on into the second radius. When reflected from the second radius to the probe no signal is observed due to the unfavourable alignment of the probe crystal. The sound wave travels on into the first/third radius, reflects back to the probe

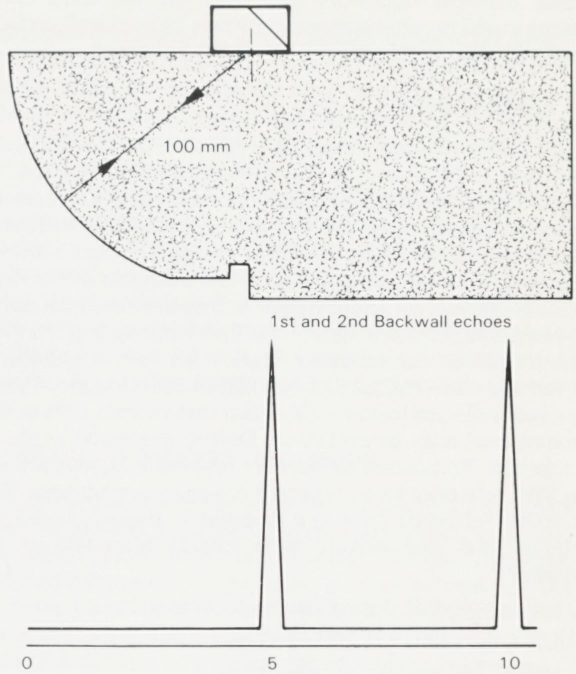


FIG. I.2

Angle probe calibration, 200 mm

and gives the second signal required for calibration. In Fig. I.3 the probe is aimed at the 25 mm radius, thus the first signal displayed represents 25 mm range. The second signal has travelled to the 25 mm radius, then to the 50 mm radius, back to the 25 mm radius and finally to the probe, representing 100 mm range. The calibration shown in Fig. I.3.3 is the one favoured by ultrasonic operators for the calibration of angle probes to show a range of 100 mm.

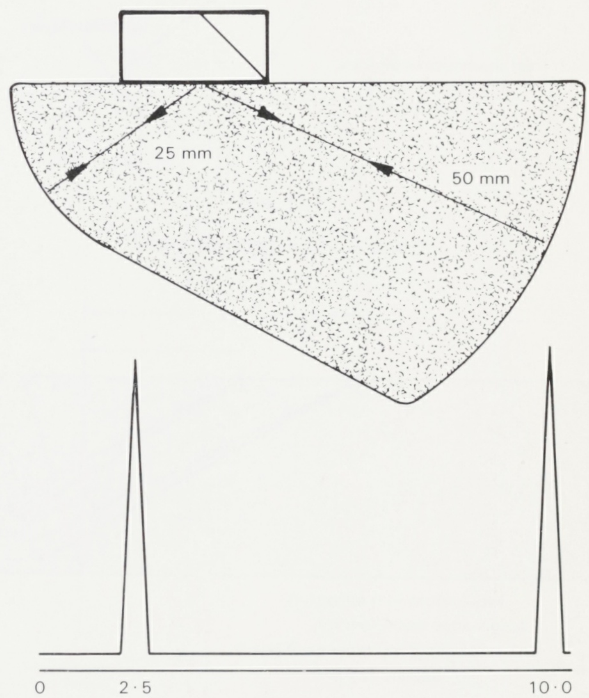


FIG. I.3

Angle probe calibration, 100 mm

2. SENSITIVITY

It is necessary to calibrate evaluation levels and reference levels so that the significance of indications can be assessed and so that different operators can work to the same level. Reflectors used to calibrate sensitivity may be backwall surfaces or drilled holes, either side drilled or flat bottomed.

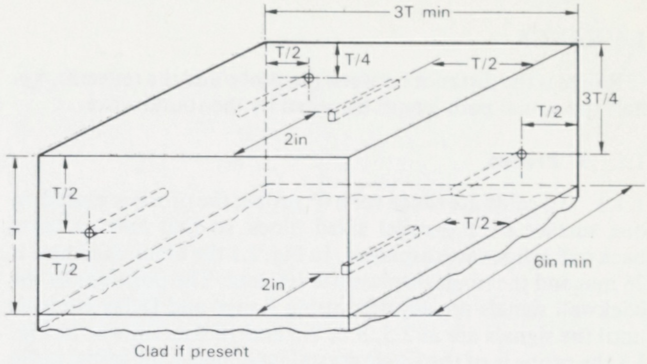
2.1 ASME Code

The ASME Code, Section V, Article 5, uses the basic calibration block shown in Fig. I.4 for angle probes and 0° probes. The dimensions of the block and the hole diameter increase as the thickness of the weld to be tested increases. Sensitivity is calibrated by adjusting the gain control until the amplitude of the highest signal reflected from one of the three holes is at 80% of the screen height. A line drawn on the screen between the peaks of the signals obtained from each of the three holes is used as the reference level. This line is sometimes referred to as the DAC or distance amplitude correction curve. Any signal reflected from a weld defect that exceeds 20% of this reference level must be evaluated. Defects evaluated as planar are rejected. Volumetric defects are ignored if signals are less than 50% reference level, reported if signals are between 50% and 100% reference level and rejected if signals exceed the reference level and defects have lengths in excess of the following:

(a) 6 mm, for weld thicknesses up to 19 mm.

(b) 1/3 t, for t between 19 and 57 mm.

(c) 19 mm, for thicknesses over 57 mm.



Weld thickness (t)	Basic calibration block thickness (T)	Hole diameter	Notch size
1in or less	¾in or t	3/32in	Width = ⅛in to ¼in
Over 1in through 2in	1-1½in or t	⅛in	
Over 2in through 4in	3in or t	3/16in	Depth = 2%T
Over 4in through 6in	5in or t	¼in	
Over 6in through 8in	7in or t	5/16in	Length = 2in min
Over 8in through 10in	9in or t	⅜in	
Over 10in see note (5)			

Fig. I.4

ASME basic calibration block

APPENDIX II

ULTRASONIC METHODS OF DEFECT SIZING

Ultrasonic methods used to assess the size of defects are based either on the amplitude of the defect signal in relation to a reflector of known size or on the extent of probe movement through which the defect signal is visible. More sophisticated methods are beyond the scope of this paper.

1. ECHO AMPLITUDE

In this method defect signals are compared with signals obtained from flat bottomed holes of agreed diameter in reference blocks of specific dimensions. Alternatively as in the AVG/DGS system, echo amplitudes are compared with theoretical disc-shaped reflectors.

The theory behind the Distance Gain Size system is that a mathematical relationship exists between the amplitude of a received signal, the size of the reflector and the distance between the probe and the reflector. Unfortunately for the D.G.S. system other unknown quantities such as defect surface roughness, defect alignment and compressive stress also affect signal amplitude but cannot be included in the mathematical expression.

D.G.S. curves are drawn on transparent scales which are fitted to the screen of the flaw detector. Scales are available for use with different flaw detectors, different diameter probes, different probe angles and different time base range calibrations.

A D.G.S. scale consists of a series of curves, Fig. II.1, each curve representing an equivalent flaw diameter and showing the maximum amplitude of any signal that can be obtained from a ıaw of that diameter when the equipment is properly calibrated.

Circles C2 and R2 are inscribed on the scales for calibration of sensitivity. The amplitudes of signals reflected from either the quadrant or the hole in the appropriate IIW block are adjusted so that the peak of the signal lies within circle C2 or R2 respectively. Further adjustments are then made to sensitivity as detailed on the scale. The choice of calibration block is determined by the size of the probe, IIW V1 and V2 blocks being used for large and small probes respectively.

For all scales, the method of use after calibration is simple. The height of any defect signal is maximised by probe movement and the highest curve intersected by the signal represents the equivalent flaw diameter of the defect. It should be stressed that the e.f.d. gives a minimum value for defect size and assumes a flat, circular reflector. In practice, defects are usually irregular in shape, have uneven surfaces and a reflectivity coefficient that is determined by the composition of the defect. Consequently, equivalent flaw diameters do not represent true defect size.

The D.G.S. Method is best suited to the examination of rolled or forged products where defects are more likely to be parallel to the testing surface. The accuracy of the method declines with increase in defect size.

For the examination of welds the D.G.S. system is best used to provide an evaluation level. All indications above the curve of, for example, a 1.5 mm equivalent flaw diameter would be recorded for further evaluation using other ultrasonic methods.

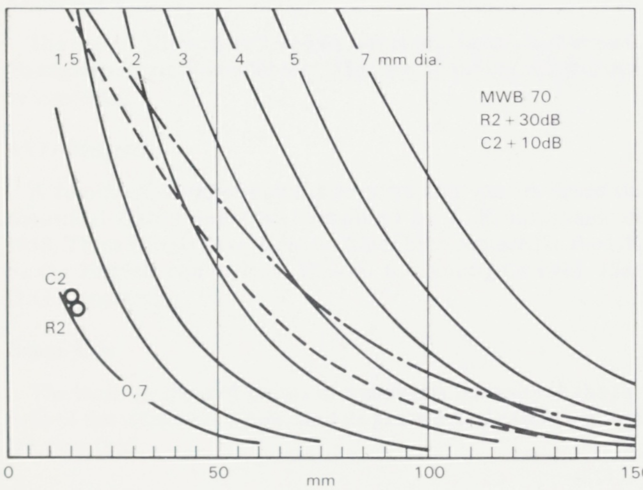


FIG. II.1

D.G.S. scale for MWB 70° probe

2. BEAM GEOMETRY METHODS

With these methods the geometry of the beam emitted by a probe is plotted by observing the responses from suitably positioned drilled holes in reference blocks. According to preference the width of the beam is taken between the points where the intensity of a sound wave is 6, 12 or 20 dB less than that at the axis of the beam. A 20 dB plot is shown in Fig. II.2.

To plot the size of a defect the procedure is reversed. The reflector is scanned and the probe positions are marked on the surface of the component, on both sides of the point of maximum intensity, where the signal amplitude has fallen by 6,

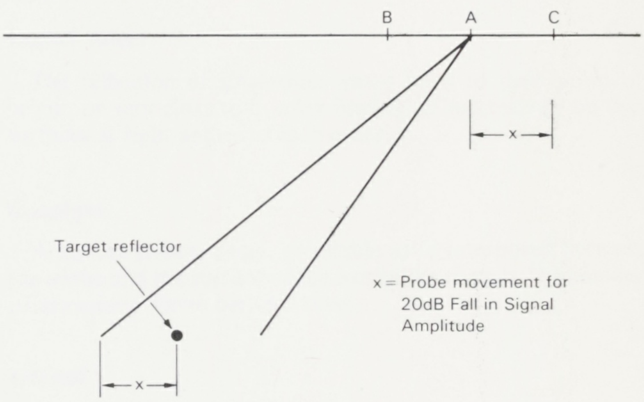


FIG. II.2

Beam plotting—20 dB extent

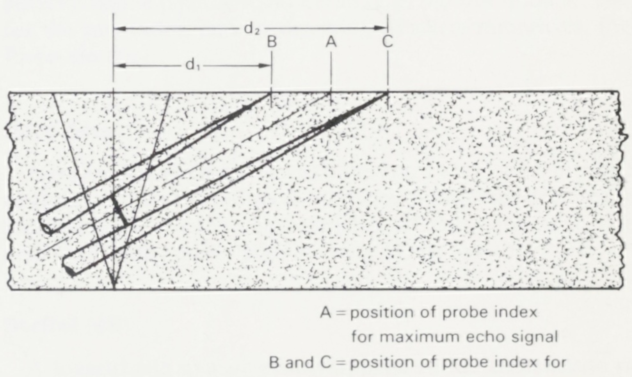


FIG. II.3

Defect size estimation

12 or 20 dB from the maximum as shown in Fig. II.3. The size of the defect may then be plotted using a protractor and ruler or a purpose built flaw location slide. The accuracy of beam geometry methods reduces as the range to the defect increases. This is due mainly to the increase in beam width with distance and also to the magnification of small errors with ruler and protractor. Another source of error is the assumption that defects act as specular reflectors. In fact, the situation is far more complex and significant differences have been observed between the behaviour of drilled holes and natural reflectors.

The use of beam geometry methods is a matter of personal preference, however, the 20 dB version is regarded as suitable for small weld defects whereas the 6 dB version is preferred for defects larger than the beam width—such as plate laminations.

APPENDIX III

GLOSSARY OF TERMS

A full glossary of terms used in non-destructive examination can be found in British Standard 3683.

1. ULTRASONIC TESTING

'A' scan Presentation

A form of cathode ray tube (crt) display in which signal strength (echo height) is represented by displacement in the vertical direction (Y axis) and time, or distance travelled, is represented by displacement along the time base (X axis).

Amplitude

The height of an echo on the crt screen; the magnitude of the input voltage impulse producing the echo signal.

Angle of Incidence

The angle between the axis of the ultrasonic beam and the normal to a surface on which it impinges, as it travels towards that surface.

Angle of Reflection

The angle between the axis of the ultrasonic beam and the normal to a reflecting surface, as it travels away from that surface in the same medium. Numerically equal to the angle of incidence.

Angle of Refraction

The angle between the axis of the ultrasonic beam and the normal to an interface between two media as it travels away from the interface into the second medium.

Angle Probe

A probe from which the beam propagates at any angle of refraction between 0 and 90°. Two kinds are in use:

Angle greater than 0°, less than 20° (compressional waves).

Angle greater than 33°, less than 90° (shear waves).

The angles quoted are for steel. Compressional wave angle probes are rarely needed for weld testing.

Attenuation

The loss of intensity suffered by ultrasonic waves as they pass through the material under test. This loss is almost entirely due to scattering.

AVG Diagram

A family of distance-amplitude correction curves based on acoustical theory and first formalised by J. Krautkrämer in 1958. These initials have in recent times been replaced in the UK by the English equivalents, D.G.S. (distance-gain-size). (*See* D.G.S. system).

Beam Axis

The locus or trace of points of maximum intensity in the far field of the ultrasonic beam, and its geometrical extension into the near field.

Beam Spread

'The divergence of the main lobe of an ultrasonic beam in the far field.'

Bottom Echo (First)

An energy pulse reflected from the boundary of a body directly opposite to the surface on which the probe (or probes) is positioned, and returned to that surface by the shortest path. (The term is generally restricted to compressional waves.)

Calibration Block

A piece of material of specified composition, heat treatment, geometric form, and surface finish, by means of which ultrasonic equipment can be assessed and calibrated for the examination of material of the same general composition.

Combined Double Probe

Two piezo-electric transducers, one transmitting, and the other receiving, mounted on blocks of Perspex or similar material, acoustically separated, but incorporated in a single housing.

Compressional Wave

A form of wave motion in which the particle displacement (particle 'orbit') is parallel to the direction of propagation, the displacement itself consisting of alternate cycles of compression and dilation. Also referred to as a longitudinal wave.

Corner Effect

The reflection of ultrasonic waves back to their point of origin, or very close to it, after impinging successively on two surfaces at right angles to each other.

Couplant

A liquid, grease, paste, or pliable solid interposed between the probe and the surface of the workpiece to assist the passage of ultrasonic waves between them.

Crystal

PROBE CRYSTAL

A piezo-electric element in the form of a wafer cut from a single (natural) crystal, e.g. quartz, or from a piece of polycrystalline (synthetic) material, e.g. barium titanate, used for the generation and/or detection of ultrasonic waves. (*See* Piezo-electric).

Dead Zone

A region immediately beneath the entry surface from which no direct echoes from discontinuities can be either detected or identified, due to the characteristics of the equipment, e.g. persistent probe noise, and/or those of the material itself.

Decibel (dB)

A logarithmic unit originally applied to the comparison of levels of electrical power, and now also used to compare sound pressures (echo heights).

Two echo signals h' and h'' are said to differ by n dB when $n = 20 \log10 h'/h''$.

Delayed Time Base Sweep

A crt presentation in which the time base spot sweep is not displayed until a chosen time interval has elapsed since the pulse was emitted. This facility is indispensable in some calibration procedures and as a supplement to the horizontal (X) shift.

D.G.S. System

A family of distance-amplitude curves originally computed for the case of compressional waves incident upon small, smooth, planar (disc) reflectors, and relating echo height to the size of the disc, its distance from the probe, and the intensity of the back echo. The curves have since been adapted for use with flat-bottomed-hole calibration blocks and shear wave probes.

Distance-Amplitude Correction Curve

(a) A curve constructed from the responses from a master target at several different ranges and subsequently plotted on the crt screen (in wax pencil) to facilitate judgement of the significance of flaw echoes.
    The target may take the form of a real flaw or of its calibrated equivalent, e.g. a drill hole, in a reference block.

(b) A curve plotted specifically for a flat-bottomed-hole target and engraved on a transparent plastic sheet for attachment to the crt screen. (*See* D.G.S. system).

Double Crystal Probe

'A probe employing two separate crystals in a single housing, one of which acts as a transmitter and the other as a detector.'

The crystal assemblies are separated by an acoustical barrier (usually cork) in order to prevent cross noise (q.v.).

Far Field

The main lobe of an ultrasonic beam where the intensity of the sound field is inversely proportional to the square of the distance from the transmitter. Sometimes referred to as the 'far zone' and the 'Fraunhofer' region.

Flaw Echo

Flaw Signal

The pulse of ultrasonic energy reflected by a discontinuity or any other type of imperfection in the weld or workpiece which is defined in the relevant specification or acceptance code as an unacceptable feature.

Focusing Probe

A probe containing either a mosaic of crystals on a concave backing or an acoustic lens made of plastic material and functioning by virtue of Snell's Law. Focusing probes have been used with success in flaw size estimation but the technique (immersion testing) is not suitable for weld examination.

Some degree of focusing is obtainable in double crystal probes by bevelling the Perspex blocks on which the crystals rest to give an angle of refraction in the workpiece of about $3\frac{1}{2}°$, and thus shortening the dead zone.

Frequency

In wave motion, the number of cycles per second. Numerically equal to the velocity of propagation divided by the wavelength.

Gain Control

An instrument control which enables the degree of amplification of incoming signals to be regulated. Two such controls are usually fitted.

Grass

A background of unwanted signals due either to the gain setting, the characteristics of the test equipment, or of the material under examination, and randomly distributed along the time base, against which flaw signals have to be identified.

Half Skip Position

A shear wave probe stand-off distance measured from the centre line of the weld joint, so that the axis of the beam traverses the cross-section of the workpiece once only and scans the undersurface of the weld where this is intersected by the above-mentioned centre line. (*See* Skip distance: Stand-off).

Hertz (Hz)

The name assigned in the international code of metric units (or so-called SI units) to the unit of frequency, e.g. a wave frequency of 20,000 cycles/sec is spoken as 20 kilo-Hertz and written 20 kHz. Two megacycles per second is written 2 MHz.

Initial Pulse Indication

A signal on the crt screen marking the instant at which a voltage impulse is applied to the transmitting crystal. Its rising edge is frequently invisible owing to time lag in the probe shoe and the consequent necessity to ensure coincidence between the time base zero and the instant at which the transmitter pulse actually enters the material under test.

Interface

Surface of Separation

A term capable of more than one definition. In the acoustical sense it is a transition region between two materials of different physical and therefore different acoustical properties, specifically of different acoustic impedance. The two materials must be in acoustical contact either by virtue of their nature, e.g. a slag inclusion surrounded by metal, or through the use of a coupling medium, e.g. probe face and entry surface.

Linearity

A property of the relationship between two varying quantities so that a change in the value of one is accompanied by a directly proportional change in the other. The graph representing the relationship (plotted on ordinary squared paper) is then a straight line.

Thus, in an ideal screen display there would be an unchanging linear relationship between signal voltage and amplifier output, i.e. echo height.

The same applies to the connection between the periodic rise and fall of sweep voltage and the speed of travel of the time base spot across the screen.

Longitudinal Wave

The name originally given by mathematicians to the type of particle displacement which engineers recognise more readily as a compressional wave.

Manual Scanning

Scanning with the probe held in the hand. It usually offers the widest choice of direction and angle of approach and for this reason is often used for the final assessment of a borderline flaw even in an automated system.

Mode Change

Mode Transformation

The process by which a wave of a given mode of propagation is caused to generate waves of other modes of propagation by refraction or reflection.

Mode change due to reflection at a boundary or an internal surface of separation, e.g. a fissure, can hinder interpretation.

Near Field

The region in an ultrasonic beam which is subject to variations of intensity due to diffraction effects. It extends from the source of radiation to a point just short of the far field. (Sometimes referred to as "Fresnel region" or "near zone".)

Noise

Spurious signals often generated by grain structure of the material.

Normal Probe

Straight Beam Probe (USA)

A probe from which waves propagate at 90° to its contact surface.

In normal testing practice this implies a compressional wave probe.

Orientation

The angular relationship between a reflecting surface and an incident wave, i.e. an attitude precisely defined.

Phase

(phys) Points in the path of a wave are said to be 'in phase' if the displacements at those points at any instant are exactly similar, i.e. of the same amplitude and varying in the same manner.

Piezo-Electric Effect

A property of certain natural crystals which, when subjected to mechanical strain, e.g. pressure, develop electric charges of opposite sign on opposing faces. Discovered by P. and J. Curie in 1881.

It is now possible to produce this effect in synthetic crystals prepared from suitably processed mineral powders.

Conversely, the application of an electric potential will induce mechanical strain, e.g. compression or dilution, between opposing faces. This so-called inverse effect is utilised when a crystal is required to transmit ultrasonic waves, and the direct effect when it is required to detect them.

Planar

Term applied to any reflector whose surface lies essentially in one plane.

Probe

An instrument consisting of a piezo-electric transducer to generate and/or detect ultrasonic waves, a backing medium to damp the transducer, an electrical lead, and a sturdy cover to protect the whole system.

Probe Index

Either one of two reference marks engraved on opposite sides of the shoe of a shear wave probe, to assist in locating the geometrical axis of the beam.

A line joining these two marks should therefore pass through the beam emission point (beam index). Where the centre of intensity does not lie on the geometrical axis it can be detected by calibration, using the curved edges of blocks A2 or A3 (BS 2704).

Pulse

Wave Packet

(gen) A short wave train.

(spec) A damped wave train employed in the pulse echo technique, so that the amplitude falls to one-tenth of its peak value in not more than five cycles.

Pulse Echo Technique

A technique in which the presence of a discontinuity in a material is indicated by the reflection of pulses from it.

Pulse Repetition Frequency (prf)

The number of pulses transmitted per second.

Range

Term borrowed from marine echo-sounding, denoting the distance from the transmitter to a reflector, measured along the beam axis.

The range is one-half of the total path length travelled by the pulse.

Rayleigh Wave

Surface Wave

A particular type of surface wave which propagates on the surface of a body with effective penetration of less than a wavelength.

Unwanted waves may be generated at the entry surface by shear wave probes of 70° angle or over.

Receiver

The detecting element of a two-probe system, or a double-crystal probe, functioning by virtue of the direct piezo-electric effect and capable (theoretically) of detecting echoes within a zone identical in spread and cross-section with the main lobe of its associated transmitter.

Reference Block

An aid to interpretation in the form of a testpiece of the same material, significant dimensions and shape as a particular object under examination, but not necessarily containing natural or artificial defects.

Reject Control

A control which permits the reduction or elimination of unwanted signals, e.g. grass.

A control designed to facilitate acceptance or rejection by the suppression of all signals whose amplitude is below a preset threshold value.

Resolution

The ability of an ultrasonic flaw detection system to give separate indication of discontinuities having nearly the same range and/or lateral position with respect to the beam axis.

Weld examination is concerned more with differences of range (depth resolution) than with those of lateral position, i.e. angular resolution, or lateral resolution.

S.A.F.T. Synthetic Aperture Focussing Technique.

A computerised system of analysing ultrasonic data to obtain improved lateral resolution and more accurate defect sizing.

Scatter

The break-up of waves through reflection at a very uneven surface, i.e. the extreme case of diffuse reflection.

Scatter also results from reflection at one or more point reflectors, e.g. a cluster of inclusions. In this case the energy is lost, not by random reflection but by dispersal over a large, expanding (almost spherical) wave front.

Sensitivity Level

(gen) A chosen degree of working sensitivity or 'flaw sensitivity.'

(spec) A gain setting chosen after an exploratory scan to assess the testing conditions and recorded by reference to an appropriate test block.

Shear Wave

A form of wave motion possible only in solids, in which the particle displacement (orbit) is at right angles to the direction of propagation. Also referred to as a transverse wave.

Single Probe System

A system in which one single-crystal probe is used for both transmission and detection of ultrasonic waves.

The term is also loosely applied to a system in which only one hand is required for scanning although the probe may contain separate transmitting and receiving crystals.

Skip Distance

A shear wave probe stand-off distance measured from the centre line of the weld joint, so that the beam impinges upon the upper surface of the weld after twice traversing the cross-section of the workpiece.

Snell's Law

A law relating to the passage of light through successive media, e.g. air and glass, which also applies to sound waves.

An ultrasonic wave passing obliquely from one medium to another is bent or refracted at the interface between the two media. Refraction occurs because ultrasound travels at different velocities in different media. The angle through which the incident wave is refracted bears the same relationship to the angle of incidence at the interface as the velocity in the second medium to that in the first.

Both angles are measured from the normal to the interface at the point where the incident wave meets it.

Sound Intensity

Energy transfer per second through unit area of a wave surface. Not to be confused with sound pressure.

Intensity is proportional to the square of the sound-pressure amplitude.

Sound Pressure

The force exerted per unit area of wave surface upon particles in that surface. In longitudinal waves the alternating compression and extension takes place at right angles to the wave surface, and in traverse waves the shearing force is exerted in a direction parallel to the wave surface.

Stand-Off

A distance measured along the surface of the workpiece from the centre line of the weld joint (or other fiducial mark) to the shear wave probe index, initially to indicate the half and full skip positions and, at a later stage, to provide a reference point for flaw location using the flaw location slide.

Suppression

Grass Cutting

Reject

The reduction of noise by suppression of all signals below a predetermined amplitude.

Many flaw detectors are fitted with a control for this purpose but in some designs suppression is a permanent feature and thus beyond the control of the tester. This is a matter for consideration when choosing equipment for a given purpose.

Surface Wave

'Any ultrasonic wave which propagates on the surface of a body.'

The surface wave of most importance in weld testing is the Rayleigh wave. The so-called Lamb wave is encountered only where the wavelength is of the same order of magnitude as the thickness of the material under test, i.e. about 4 mm, and less.

Surface Wave Probe

A probe, similar in appearance to a shear wave probe, designed to give an angle of refraction of 90°. (Angle of incidence in the probe shoe 58-60°, varying from one batch of Perspex to another).

Swept Gain

A design feature whereby echoes from reflectors at relatively long ranges appear on the screen at the same height as those from reflectors close to the probe. Useful in cases where attenuation in the workpiece is high.

Tandem Probe

A system when two or more probes are placed in line facing the weld so that a pulse emitted by one probe will be reflected off a defect and be received be another probe in the line.

Time Base

A horizontal trace on the screen of a crt, and generated in such a way that distance along it is proportional to time.

This trace is the persistent image of a luminous spot which appears when a pulse is launched and whose transit time (from left to right) therefore bears a strict relationship to the distance travelled by the pulse. The control which determines the time base setting is labelled 'Range'.

Total Attenuation

The diminution of intensity of a particular wave mode during one round trip in the workpiece, resulting from the combined effects of absorption, scatter, and geometric beam spread.

Absorption is a marginal influence, scatter and beam spread the dominant ones.

Transceiver

A probe in which the same crystal is used both to generate and detect ultrasonic energy.

Transducer

Any device which, when actuated by energy of one kind, converts it directly into energy of some other kind.

A probe crystal is a 'bilateral, electromechanical transducer' because, by virtue of the reverse piezo-electric effect, what is normally its output, i.e. electrical energy, can be used as input.

Ultrasonic Frequency

Any frequency of vibration beyond the upper limit of audibility of the human ear, generally considered to be greater than 20 kHz (in the young).

Velocity of Propagation

(gen) Where the thickness of the test material is much greater than the wavelength of the transmission, the effective velocity is the group velocity, i.e. the velocity of the group of waves included in the pulse envelope. This can be measured by timing the transit of a pulse using some feature of the envelope as a reference point, e.g. the leading edge.

Wave

A cyclic disturbance of the particles of a medium conveying energy.

A wave may be progressive as in flaw detection or stationary as in wall thickness measurement.

The graphical representaion of a wave is the well-known sine wave, i.e. the locus of the particle displacement through one complete cycle (during which time the wave motion moves forward one wavelength).

Wavelength

The distance, measured along the line of propagation, between two wave surfaces in which the phase differs by one complete period.

Usually illustrated in textbooks as the distance between identical crests in two successive waves.

Numerically, the wavelength is equal to the velocity of propagation divided by the wave frequency.

Zero Angle Probe

Normal Probe

Straight Beam Probe (USA)

A compressional wave probe in which the angle of incidence is 0°, i.e. the beam axis coincides with the surface normal.

2. RADIOGRAPHY

Absorbed Dose

Of an ionizing radiation. The energy per unit mass imparted to an irradiated material. Expressed ideally in ergs per gramme, the unit being the 'rad', but for X-rays or gamma rays of quantum energies up to 3 MeV, the röntgen may be used.

Absorption

The reduction in intensity of a beam of radiation during its passage through matter.

Absorption Coefficient

Of a uniform substance for a parallel beam of homogeneous radiation. The ratio of the rate of decrease, in the direction of propagation, of the intensity at any point to the intensity at that point.

Anode

The positive electrode of a discharge tube. In an X-ray tube the anode usually carries the target.

Back-Scatter

That part of scattered radiation which has a scattering angle of more than 90°.

Background Radiation

Ionizing radiation, other than that to be measured, which contributes to natural leak and/or background count.

Betatron

An apparatus in which electrons are accelerated in a circular orbit of constant radius by means of electric force associated with a varying magnetic field.

Cassette

A light-tight container for holding an X-ray film under uniform pressure during exposure.

Cathode

The negative electrode of a discharge tube.

Characteristic Curve

A curve, for a photographic film, relating the common logarithm of exposure and the photgraphic density achieved under specified processing conditions.

Constant Potential

A unidirectional voltage of constant magnitude. In practice, a small periodic variation may occur, called Ripple Voltage.

Contrast

The relative brightness of two adjacent areas in a radiograph, photograph reproduction or fluorescent screen image.

Curie

A unit of radioactivity; the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10}. Abbreviation: c.

Definition

The sharpness of delineation of image detail in a radiograph, photographic reproduction or fluorescent screen image.

Densitometer

An instrument for measuring photographic transmission and/or reflection density.

Density

The darkness of a radiograph. Expressed mathematically as the logarithm of the ratio of the intensity of incident light to that of the light transmitted through the film.

Development

The conversion of a latent image into a visible image by treatment of the emulsion with a suitable chemical solution (the developer).

Dose Rate

The rate, with respect to time, at which radiation is delivered. It may be expressed in röntgens or rads per unit time.

Electromagnetic Radiation

Radiation associated with a periodically varying electric and magnetic field. It exhibits phenomena characteristic of transverse wave motion. 'In vacuo' it travels with velocity of approximately 3×10^{10} cm/sec.

Electron Volt

A unit of energy. The kinetic energy acquired by an electron when accelerated through a potential difference of one volt. (One eV equals 1.602×10^{-12} erg. One Mev equals 1.602×10^{-6} erg.) Symbol eV.

Emulsion

Photographic emulsion; a suspension of photo-sensitive material, such as silver halide grains, in a medium such as gelatine.

Exposure Chart

A chart indicating the radiographic exposures appropriate for different thicknesses of a specified material.

Filament

The heating element of a hot cathode.

Film Badge

A photographic film used as a radiation monitor; often partially shielded to differentiate between types and qualities of ionizing radiation.

Film Contrast

The effect of the film characteristics on radiographic contrast. A measure of this is given by the slope of the characteristic curve at the relevant density.

Filter

Material interposed in the path of radiation in order to reduce selectively the intensity of radiation of a certain range of wavelengths or energies.

Fixing

The chemical removal of unused silver halides from an emulsion after development. A fixing bath may be acidified (acid fixing bath), primarily to prolong its life.

Flaw Sensitivity

The minimum detectable thickness of a specific flaw measured in the direction of the radiation beam, expressed as a percentage of the total thickness of a specimen of specified homogeneous material.

Fluorescence

Luminescence which occurs during the period of irradiation.

Fluorescent Screen

A suitably mounted layer of material (e.g. barium platino-cyanide or zinc sulphide) which fluoresces in the visible region of the spectrum under the action of X-rays or other ionizing radiation; used to give a visual image of an irradiated object.

Focal Spot

The area of the target on which the electron stream impinges and from which X-rays are emitted. Also called 'Focus'.

Focus-to-film Distance

The distance from the focus of an X-ray tube to a film set up for radiographic exposure. Abbreviation: f.f.d.

Gamma Radiography

Radiography by means of gamma rays.

Half-life

The time in which the amount of a radioactive nuclide decays to half its initial value.

Half-value Thickness (Half-value layer)

The thickness of a specified substance which, when introduced into the path of a given beam of radiation, reduces its effect to one half. It may be used as an indication of the quality of the beam or the opacity of the substance. Abbreviation: H.V.L.

Identification Marker

A marker, usually of heavy metal, used to provide a reference point or identification mark in a radiograph.

Image Intensifier

A device used in fluoroscopy, incorporating a vacuum tube in which electrons released by X-rays from a special screen, are accelerated and focused on to a fluorescent screen; gives a brighter image than that of X-rays on a fluorescent screen.

Image Quality Indicator

A device incorporating elements of different radiation opacity, which is used for judging, from the appearance of its image in a radiograph, the overall quality of that radiograph.

I.Q.I. Sensitivity

The smallest change in object thickness which can be detected in a radiograph, expressed as a percentage of the total thickness, the object being assumed to be of specified homogeneous material.

Inherent Fog

Unwanted blackening of an emulsion caused by the development of grains which are inherently developable without exposure. This type of fog varies with the age of the emulsion and with conditions of storage.

Intensifying Factor

The ratio of the exposure time without intensifying screens to that when screens are used, other conditions being the same.

Intensifying Screen

A layer of suitable material e.g. lead foil, which, when placed in close contact with a photgraphic emulsion, adds to the photographic effect of the incident radiation.

Isotopes

Nuclides having the same atomic number but different mass numbers.

Latitude

Of an emulsion. The range in exposure corresponding to the useful density range.

Microradiography

Radiography of thin sections of material in such a way that the resulting image may be enlarged to reveal microstructure.

Milliampere-second

A measure of X-ray exposure expressed as the product of the milliammeter reading and the time of exposure in seconds. Larger units such as milliampere-minutes or milliampere-hour can be used.

Millicurie-hour

A measure of gamma-ray exposure, expressed as the product of the radioactivity of the source in millicuries and the time of exposure in hours. The larger unit 'curie-hour' can also be used.

Penumbra

The partial shadow extending beyond the edges of the main shadow (umbra) of an object, due to the finite size of the source: the width of this partial shadow.

Pressure Mark

A variation in photographic density caused by the application of local pressure to the emulsion; the mark may be light or dark according to circumstances.

Primary Radiation

Radiation which is incident on the absorber and which continues unaltered in photon energy and in direction after passing through the absorber.

Processing

A series of operations, such as developing, fixing, and washing, associated with the conversion of a latent image into a stable, visible image.

Quantum

The smallest quantity of energy that can be associated with a given phenomenon. The quantum of electromagnetic radiation of a particular frequency is given by the product of the frequency and Planck's constant h. ($h = 6.624 \times 10^{-22}$ erg-second).

Rad

The unit of absorbed dose. It is 100 ergs per gramme.

Radioactivity

Spontaneous nuclear transformation and the phenomena associated therewith.

Radiograph

A photgraphic image produced by a beam of penetrating ionizing radiation which has passed through an object.

Radiographic Contrast

Contrast in a radiograph; usually expressed in terms of density difference.

Radiographic Exposure

The subjection of an emulsion to radiation for the purpose of producing a latent image; commonly expressed in milliampere-seconds or millicurie-hours.

Radiographic Range

The maximum range of thickness of a specified homogeneous material, or of radiation opacity of an object, which can be recorded satisfactorily in a single radiograph with a specified technique.

Reciprocity Law

A law which states that, all other conditions remaining constant, the time of exposure required to produce a given density is inversely proportional to the intensity of the radiation.

Rem

Röntgen-equivalent-man/mammal. The absorbed dose of any ionizing radiation which has the same biological effect as one rad of X-radiation.

Resolution

The smallest distance between recognizable images on a film or screen. It may be expressed as the number of lines per millimetre which can be seen as discrete images.

Reticulation

An effect due to rupture of an emulsion coating, usually caused by rapid changes of temperature or of chemical condition of the emulsion when wet. It gives an appearance similar to the grain of leather.

Rhm

Pronounced 'rum'. Röntgen-per-hour-at-one-metre. A unit of effective strength of a gamma-ray source under specified conditions of shielding, such that at a distance of one metre in air its gamma rays produce a dose rate of one röntgen per hour.

Röntgen

A unit of dose, defined as the quantity of X-ray or gamma radiation such that the associated corpuscular emmission per 0.001293g produces, in air, ions carrying one electro-static unit of quantity of electricity of either sign. Abbreviation: r.

Rod-Anode Tube

An X-ray tube in which the target is situated near the end of a long tubular anode.

Salt Screen

An intensifying screen consisting of a material such as calcium tungstate, which fluoresces in the visible or ultra-violet region of the spectrum under the action of X-rays or other ionizing radiation.

Scattering

The redirection of radiation, with or without change of quantum energy, during its passage through matter.

Screen-Type Film

X-ray film designed for use with salt screens. It is sensitive to the fluorescent light emitted by such screens under the action of X-rays.

Secondary Radiation

Radiation, other than primary radiation, emerging from the absorber.

Source-to-Film Distance

The distance from a source of radiation to a film set up for a radiographic exposure. Abbreviation: s.f.d.

Specific Activity

The activity of a material containing a radioactive substance, expressed in any convenient unit, e.g. curies-per-gramme or curies-per-cubic centimetre.

Spectrum

The orderly separation of the components of a beam of radiation according, for example, to their wavelengths, frequencies or quantum energies.

Speed

The characteristic of an emulsion which determines the exposure required under any given set of conditions.

Step-Wedge

A block of material in the form of a series of steps, used to compare the radiographic effects of X-rays or gamma rays under various conditions.

Stop Bath

An acid bath to arrest development and to neutralize alkaline developer in an emulsion before transfer to the fixing bath.

Subject Contrast

Contrast arising from variation in radiation opacity within an irradiated object.

Target

The surface of the anode of an X-ray tube on which the electron stream impinges and from which the main beam of X-rays is emitted.

Tube Head

A type of tube shield which, in addition to the X-ray tube, may contain part of the high-voltage generator.

Tube-Shift Radiography

The process of finding the position and dimensions of details within an object by measurements made on radiographs taken from different directions.

Under-Development

Development which is less than that required to produce the optimum results in a particular radiograph. It may result from inadequate time, temperature or agitation, or from use of an exhausted developer.

Unsharpness

A quantitive measure of lack of definition. It is usually expressed as the width of the band of changing density or brightness arising from a sudden change in the intensity of radiation incident on the film or fluorescent screen.

Useful Density Range

The range of density over which the gradient is adequate for the recognition of image details. The upper limit is determined mainly by the brightness available in the film illuminator; the lower limit by the sensitivity required.

Wetting Agent

A substance used in processing to reduce surface tension. Often used in a final bath to assist rapid and uniform drainage of the film and so to reduce the occurrence of drying marks.

X-ray Film

A film base which is coated, usually on both sides, with a photographic emulsion designed for recording X-rays.

X-ray Paper

White paper coated with photographic emulsion, for use with or without an intensifying screen.

X-ray Tube

A discharge tube for the production of X-rays.

X-rays

Electromagnetic radiation resulting from loss of energy of charged particles (e.g. electrons) and having shorter wavelength than ultra-violet radiation.

3. MAGNETIC PARTICLE TESTING

Alternating-current Magnetization

Magnetization by the magnetic field induced when alternating current is flowing.

Arc

A luminous high temperature discharge produced when a current of electricity flows across a gap.

Black Light

Near ultra-violet radiation (3000 to 4000 ångströms) used for exciting fluorescence.

Black Light Filter

A filter which suppresses visible light and ultra-violet radiation other than black light.

Burning

Local overheating of the component at the electrical contact area arising from high resistance or the production of an arc.

Circumferential Magnetization

Magnetization which establishes a flux around the periphery of a component.

Coil Technique

A method of magnetization in which part or the whole of the component is en-circled by a current-carrying coil. (The use of the term is usually restricted to instances in which the component does not form part of a continuous magnetic circuit for the flux generated.)

Current Flow Technique

A method of magnetizing by passing a current through a component via prods, contact heads or clamps. The current may be alternating, rectified alternating or direct.

Diffuse Indications

Indications that are not clearly defined. e.g. indications of sub-surface defects.

Dry Powder Method

The application of magnetic particles without the use of a liquid carrier.

Ferro-Magnetic

Having a permeability which can be considerably greater than that of the air and can vary with flux density.

Fluorescent Magnetic Ink

A fluid containing magnetic particles and fluorescent materials which permits the detection of flaws by black light.

Furring

Build-up of magnetic particles due to excessive magnetization of the component under examination.

Longitudinal Magnetization

Magnetization in which the flux lines traverse the component in a direction essentially parallel to its longitudinal axis.

Magnetic Field

The space in the neighbourhood of an electric current, or of a permanent magnet, throughout which the forces due to the current or magnet can be detected.

Magnetic Field Leakage

The loss of magnetic field strength due to discontinuities and changes in section in a magnetic circuit.

Magnetic Field Strength

The measured intensity of a magnetic field at a point, usually expressed in oersteds.

Magnetic Flaw Detection Ink

A detecting medium consisting essentially of magnetic particles in a carrier liquid.

Magnetic Flow Technique

A method of magnetization in which the component or a portion of it closes the magnetic circuit of an electromagnet or permanent magnet.

Magnetic Flux

A phenomenon produced in the medium in the neighbourhood of electric currents or magnets. The amount of magnetic flux through any area is measured by the quantity of electricity caused to flow in an electric circuit of given resistance bounding the area when the circuit is removed from the magnetic field. It is proportional to the product of the quantity of electricity and the resistance of the circuit.

Magnetic Permeability (μ)

The ratio of the magnetic induction (B) to the external magnetic field (H) causing the induction.

Magnetic Particle Flaw Detection

A process for detecting surface or near-surface discontinuities in magnetic materials by the generation of a magnetic flux within a component and the application of suitable magnetic particles to its surface to give an indication of the defect.

Magnetic Poles

The points in a magnet which are the apparent seat of the external magnetic field.

Magnetic Saturation

The stage at which any further increase in the magnetic field applied to a magnetized component will fail to show any significant increase in the magnetic flux in that component.

Permeability (Absolute)

Of a material or medium. The ratio of the magnetic flux density to the magnetic field strength producing it.

Portable Flux Indicator

A particular type of reference piece used for checking the efficiency of magnetic particle flaw detection processes by placing it in contact with the component under examination.

Prods

Hand-held electrodes attached to wander cables to transmit the magnetizing current from the source to the component under examination.

Reference Pieces

Specimens containing controlled artificial defects or natural defects used for checking the efficiency of magnetic particle flaw detection processes.

Residual Magnetism

The magnetism remaining in a component when, after initial magnetization, the magnetizing force is reduced to zero.

Threading Bar Technique

A method of magnetization in which a current-carrying bar or cable is passed through a bore or aperture in a component under examination.

Threading Coil Technique

A development of the threading bar method in which a magnetizing coil rather than a straight run of bar or cable is threaded through a bore or aperture in a component.

Yoke

Of an electromagnet. A piece of ferro-magnetic material, not surrounded by windings, forming a fixed part of the magnetic circuit and serving to complete that circuit.

Lloyd's Register Technical Association

71 Fenchurch Street, London, EC3M 4BS

Telephone 01-709 9166 Telex 888379 Cables Committee London EC3

Date 21 June 1982

The 1982 Annual General Meeting

Your Committee has arranged that a copy of the Minutes should be available to every member, to inform them of the administrative and financial matters concerning the Technical Association.

It is my hope that such information may provide an incentive to members to participate more in the effectiveness of the Association.

In the case of overseas members, there has been created a post of Hon Assistant Secretary for Corresponding Members to provide more ready means of communication.

With this added organization and information now available, should you wish for an item which concerns the Association to be considered at Committee Meetings, or at the next AGM to be held in May 1983, then please contact your local corresponding member or write directly to the Assistant Hon Secretary for Corresponding Members.

Your Committee warmly welcomes your contribution and participation.

Yours sincerely

W H Marsden

W H Marsden
President

WHM/JO

LLOYD'S REGISTER TECHNICAL ASSOCIATION

MINUTES OF THE 1982 ANNUAL GENERAL MEETING

The Annual General meeting of the Technical Association was held in the Committee Luncheon Room on Wednesday 26th May 1982 at 1500 hours.

The President of the Association, Mr S N Clayton, occupied the chair.

The proposed Agenda was as follows:

1. Apologies for absence.
2. Approve and sign minutes of the last AGM.
3. Matters arising from the last AGM.
4. President's Review.
5. Proposed Syllabus for 1982/83 Session—Chairman of the Sub-Committee on Technical Papers.
6. Report of Sub-Committee on Awards to Best Authors.
7. Treasurer's Report.
8. Proposed changes to the LRTA Rules.
9. Election of Officers for the 1982/83 Session.
10. Election of Committee for the 1982/83 Session.
11. Newly elected Officers to assume posts.
12. Any other business.

Each item on the Agenda was dealt with as follows:

Item 1

Apologies for absence had been received from Mr A C Wordsworth, Dr R Nataraja and Mr R F Munro.

Item 2

The minutes of the last AGM, held on the 6th May 1981, were examined by the members present. An amendment to page 6 was proposed by Mr J S Carlton. On a motion proposed by Mr N A Dawson and seconded by Mr Carlton, the minutes were unanimously approved as amended and signed by the Chairman.

Item 3

The Chairman asked the Hon Secretary if there were any matters arising from the minutes.

The Hon Secretary replied that there were three items as follows:

(i) Concerning page 2–Item 3: The Hon Secretary advised the meeting that Index and Title cards for the Associations Ring Binders had been discussed at the First Meeting of the Committee and as Messrs Swift Print had shown little interest, and since at that time ring binders were not selling well, the Committee had decided to take no further action. The matter was now closed.

(ii) Concerning page 5–Item 5–2nd paragraph: The Hon Secretary advised the meeting that the Committee had considered the suggestion of having papers that were prepared for external publication and symposia published where appropriate as LRTA papers and that Mr Rapo's paper on Ro-Ro ships was an example of this.

(iii) Concerning page 6–Item 6–4th paragraph: The Hon Secretary advised the meeting that the procurement of designs for the proposed Association's Medal would be dealt with under Item 6 of the Agenda.

There were no comments from the floor.

Item 4

In his review of the past year the President Mr S N Clayton said:

'The 1981/82 Session had been an active and full session. A wide variety of subjects had been covered at our meetings and the high standard expected had been maintained.

There had been a good start to the Session, with an outstanding film being shown called "Three in One" by Smit Tak concerning the salvage of the *Betelgeuse* in Bantry Bay. The film was shown to two large appreciative audiences in HQ. The Association was grateful to Smit Tak International for this opportunity and especially to their representative for attending and answering our many questions.

Five of the seven papers originally proposed at last year's AGM were read to the Association:

1.	Lifting Appliances	by P Holland
2.	Data Storage and Retrieval	by C J J Beart
3.	Work of the Specification Services Department	by D S Crawford and R M Hobson
4.	GUEST LECTURE—Lloyd's of London Press	by D J Piggott
5.	Structural Design of Ro-Ro Ships	by B Rapo

Attendances were good, when weather and travelling conditions permitted, and lively discussions followed the lectures.

Unfortunately, the situation in Poland prevented Mr Kwiatkowski's paper on Diesel Engines from being published. Also, transfer and his training programme prevented Mr Fegan from writing a paper on Hydrofoils.

Nevertheless we had an unexpected bonus to fill the gap at the end of the Session when Mr Smedley very kindly offered to give a lecture on "Brittle Fracture—Land and Marine Structures". This was an outstanding lecture, very well attended by an interested audience and the Association is very grateful to Mr Smedley for assisting us in this way.

Behind the scenes the Committee of the Association has been active and several sub-committees have been working hard to further the various interests of the Association:

Sub-Committee on Technical Papers has arranged a full and varied syllabus for the forthcoming session and we shall be hearing the details of this from the Vice-President, Mr Marsden shortly.

The Sub-Committee on Awards to Best Authors has finished it's monumental task of establishing an awards scheme.

You will remember that last year the Awards scheme was agreed in principal by the AGM with only the final details of the design of the medal and the Society's financial backing outstanding. We shall be hearing more of this from Mr Carlton later in the meeting, together with the details of the proposed redistribution of the Corresponding Members on a more rationalized basis for implementing a fair adjudication procedure.

A working group was set up by the Committee to look more fully into the question of membership, including associate membership and as a result there are some proposed changes in the Technical Association's Rules to be considered later in the Agenda.

It is very encouraging to note that our Corresponding Members in the Outports have also been playing a greater part in the affairs of the Association. Letters were sent to all 43 Corresponding Members seeking their opinions on the proposed redistribution of Corresponding Members and 40 replies have been received to date. The Committee is very appreciative of this response and grateful to all those members who corresponded, particularly as their working conditions are often much more onerous than their colleagues in HQ.

Nevertheless, the number of contributions to the discussion paper has been disappointing and I urge all our colleagues in the outports to take a more active part in this aspect of the Association's affairs. After all for many technical subjects the views and opinions of the surveyors in the field is greatly respected and would make worthy contributions to the annals of the LRTA.

With the greater participation expected from the Corresponding Members, especially resulting from the Awards Scheme, the Committee has decided that a second Assistant Honorary Secretary with special responsibility for the Corresponding Members should be appointed to help the Hon Secretary and relieve his ever increasing workload. Hopefully this will also further encourage the Corresponding Members to correspond.

Looking to the future we must seek and obtain more papers of first class quality suitable for publication as both internal papers and to obtain greater involvement from our colleagues in the Outports.

I would like to specially thank Mr Marsden, Mr Wehrle and Mr Boltwood for their very valuable assistance during my term of office, and also the other members of the Committee for their support'.

The President also advised that a letter from Mr Whitehouse, the corresponding member from Newcastle, had been received thanking Mr Gresham and Mr Oxford for their presentation of the Discussion on Crude Oil Washing, at Newcastle on 12th May, which had been attended by 65 members and guests. The meeting in Newcastle was regarded as being a worthwhile venture and Mr Whitehouse asked if the Committee would consider when further meetings on other papers of particular interest to surveyors in the field could be arranged.

There were no comments from the floor.

ITEM 5

The Chairman then called upon Mr W H Marsden the Vice-President and Chairman of the Sub-Committee on Technical Papers. Mr Marsden said:

'I have noted from previous minutes, that the usual hardy annual from your Chairman of the Sub-Committee on Technical Papers is one concerning the continuing need for papers. As you know the individual workload placed on Authors in preparing a formal paper requires the encouragement and involvement of the Managements of Countries, Regions and HQ Departments.

During my year as Chairman of the Sub-Committee I have already been reminded that the difficulties in obtaining papers from Outports and Overseas are due to reasons such as the tremendous workloads, daily rates etc. This fact coupled with restricted subject material seems to limit any potential Authors and response to discussions to an absolute minimum.

However, the major factor concerning the lack of response must be the individual workload required for a formal paper; even when this could be shared by two or even three authors, especially with a sympathetic Manager.

Looking back over this last year, I am grateful to the President for his encouragement and efforts in assisting the Sub-Committee and also to a number of HQ Departmental Managers both in London and Croydon, who have also become involved.

It is due to this encouragement to the Authors that the Sub-Committee have been successful in obtaining six interesting papers for the coming session and we would like to record our acknowledgement of the work which these Authors are committed to.

My Sub-Committee has received the approval of the Committee to limit the programme to 5 papers per year. Therefore, we have one paper in reserve. I only hope the Authors of the sixth paper are continuing to progress it, so that in fact it is a reserve paper.

This approved programme is now put to this meeting for ratification; details are as follows:

1.	Non-Destructive Examination in the Society.	Mr R Porter
2.	Fire Protection, Detection and Extinction in Offshore Installations.	Mr G Coggon and Mr C M Magill
3.	Some Fundamental Principles of Good Marine Engineering Practice and Safety.	Mr R F Munro
4.	Development of Offshore Units for Use in European Waters.	Mr A J Sanders
5.	Reliability and Safety Assessment Methods for Ships and Other Installations.	Dr D S Aldwinckle and Mr R V Pomeroy

Reserve Paper, or to be read in the subsequent session:

6.	The Containment of Bulk Liquid Chemicals in Ships.	Mr J C Adam and Mr A J Johnston

I would like to advise you of another item, which comes under the heading of Administration. During my term of office I have been amazed at the amount of work that is required between the period once the paper has been written to the time when the paper is published. The Sub-Committee have now agreed to a detailed timetable which requires the Authors to have a paper written 6 months before publication. One benefit of such a timetable will enable a minimum of disruption to a proposed programme, due to the Society's work pressures which, for different reasons, could affect each of the 13 items listed.

As I shall be leaving my position of Chairman of the Sub-Committee, I would like to thank the members of the Sub-Committee for their assistance and to the Hon Secretaries for their tremendous efforts on behalf of the Sub-Committee and in particular to Mr J J Goodwin whom I acknowledge had done the hard work in preparing the proposals I have placed before you'.

At this point the Chairman invited comments from the floor prior to ratification of the proposed syllabus.

Mr B Wilson noted the proposed dates were earlier in the month than usual. The Assistant Hon Secretary explained that the dates had been changed to correspond to the first Wednesday in each month, in accordance with the Association's Rules. On a motion proposed by Mr Wilson, and seconded by Mr D K Hart, the proposed syllabus for the 1982/83 Session was unaminously approved.

Item 6

The Chairman then called upon Mr J S Carlton, the Chairman of the Sub-Committee on Awards to Best Authors. Mr Carlton said:

'Since the last AGM approval has been received from the Society to purchase 20 medals complete with ribbons. Accordingly, after final approval of the medal design, an order was placed with Messrs Fattorini in September of last year. Manufacture of these medals was now nearing completion and their delivery is expected during the latter part of this summer.

Subsequent to the provisional approval of the "Report of the Sub-Committee on Awards" dated July 1981 by the Committee, the Sub-Committee was re-constituted in order to examine the distribution of corresponding members of the LRTA.

This re-constitution of the Sub-Committee was initiated because the first report recommended the involvement of the corresponding members in the award adjudication procedure in order to give the widest possible appreciation of the papers presented. It was, however, noted that the existing distribution of corresponding members required modification in order to reflect the present distribution of the membership. Consequently, the terms of reference of the Sub-Committee on Awards was to seek a more rational basis for the distribution of corresponding members.

As such the Sub-Committee proposed that the re-distribution of corresponding members be put on a regional basis rather than the country or office based system which is in use at the present time. Furthermore, the proposed system is designed to give representation to all Surveyors of the Society which is not currently the case. The geographical boundaries of the proposed regions have been determined by trying to resolve the following set of constraints:

(i) The geographical location and number of Surveyors in particular areas.

(ii) The managerial regions already established by the Society.

(iii) The locations of existing corresponding members.

(iv) The existence of any extreme political differences between countries.

This study has resulted in the proposal of 31 regions, and each is to be presided over by one corresponding member of the Committee. This contrasts with the existing arrangement which comprises 43 corresponding members. Wherever possible, it is proposed that the existing corresponding members are redeployed in the new-regions.

Upon the instructions of the Committee, the Sub-Committee has sought the views of the 43 existing corresponding members on our proposals. We have had replies in all but 3 cases. We have analysed all the replies received and have found only one non-favourable reply and one non-committal reply. The remaining 38 replies have all expressed their support and encouragement for the proposals, even though some of the offices will be losing their direct contact with the Association. Many of the replies also contained helpful suggestions concerning communication problems between countries and also the offer of new corresponding members. These have been taken into account wherever possible. In particular we would amend our proposals as detailed in Table 2 of our report as follows:

(i) North African Region to include Kenya which was formerly in the South African Region.

(ii) The corresponding member for the Central Orient Region to be located at Seoul.

In conclusion, therefore, we would report that the Supplementary Report of the Sub-Committee on Awards dated March 1982 has received an extremely favourable response from the corresponding members to the Committee'.

There were no comments from the floor.

ITEM 7

The Chairman called upon the Association's Hon Treasurer, Mr D T Boltwood, to give his financial report.

Mr Boltwood said:

'We have now completed another year and I am pleased to report the Association's monetary affairs are in a reasonably satisfactory state.

The Association's Bank Balance on the 31st March 1982 stood at £406.11 despite the usual expenses and gratuities incurred during the current session.

This large Bank Balance has accrued primarily from the sale of LRTA Binders which has been really quite remarkable and unexpected. Notwithstanding the gloomy predictions I made in my last AGM Report concerning future sales, we have managed to sell 219 binders to members of the Association since April 1981. In monetary terms this amounts to £405.35 and must be a record for one session.

It is my opinion that the stimulus for this tremendous sales figure has been created by the introduction of the "pink" order form which you will all have seen when distributed with LRTA papers during the session. I think we must congratulate Mr Goodwin for his proposal regarding its introduction made at the First Committee Meeting of the last Session.

During the course of the Session the Association's finances were reviewed and to some extent simplified. Briefly, this has resulted in the Association receiving from the Society an annual grant of £100 for the next three years and an undertaking by the Association to repay the £1400 loan with regular instalments. You will be pleased to learn that one instalment of £250 has been made and that because of the cash in hand the Committee has agreed to make another instalment of £250 in the near future.

At the last AGM I reported that, overall, the Association was running at a loss amounting to £36.69. This year I am pleased to advise that the overall loss has been reduced to £19.53 and it is hoped that with the aid of next year's grant this loss can be completely eradicated.

Copies of the Income and Expenditure Account and the Balance Sheet for the year ended 31.3.82 are tabled here for your consideration.

This meeting sees the end of my term as Treasurer, a position I have held for two years and enjoyed immensely. I am sure the next Treasurer will also find it enjoyable'.

Mr R J Hook, noting the item of £1400 loan from Lloyd's Register, asked whether the Association now received a loan from the Society in place of a grant. Mr Boltwood advised that the item arose from a loan obtained from the Society to pay for the Association's Ring Binders. The proceeds from the sale of the binders at £1.85 each, cost to the Association £1.84 each, were periodically repaid to the Society. As the Association has no income of its own, it was necessary to obtain a grant from the Society to cover its expenses. The present grant of £100 per annum has been agreed for a period of three years.

ITEM 8

The Chairman advised the meeting that during the past year a working group under the chairmanship of Mr Marsden had been set up to look at the question of membership and associate membership of the Association. At the third meeting of the Committee the findings of the working group had been discussed and as a result the changes to the Association's Rule 3 and Rule 4 were now proposed in order to clarify the question of elegibility to membership and associate membership. The proposed changes were:

Rule No.3

Existing: 'The membership shall in general, consist of the Technical Staff of Lloyd's Register of Shipping and shall be known as Members of the Technical Association. Non-Technical Staff may join the

Association, subject to the approval of the Committee of the Association, and shall be known as Associate Members of the Technical Association'.

Proposed: 'The membership of the Technical Association shall consist of Members and Associate Members. A Member of the Association shall be a member of the Technical Staff of Lloyd's Register of Shipping as defined in his terms of appointment.
Non-Technical Staff, who hold the equivalent of a pass degree of a University in a scientific or technological subject related to the work of the Society, may join the Association subject to the approval of the Committee of the Association and shall be known as Associate Members of the Technical Association. Associate Members may contribute or discuss papers and give or attend lectures'.

Rule No. 4

Existing: 'The members of the Association shall elect a Committee, Corresponding Members of the Committee, a President, Vice-President, Honorary Secretary, Honorary Treasurer and Assistant Honorary Secretary to represent the Association and arrange its procedure. An Annual General Meeting shall be held in May and Committee Meetings shall be arranged as required'.

Proposed: 'The Members of the Association shall elect a Committee, Corresponding Members of the Committee, a President, Vice-President, Honorary Secretary, Honorary Treasurer and Assistant Honorary Secretaries to represent the Association and arrange its procedure. An Annual General Meeting of Members shall be held in May and Committee Meetings shall be arranged as required. Associate Members are not entitled to attend the AGM'.

The Chairman also advised:

'With reference to Rule No. 8, it is the wish of the Committee to inform the AGM that they wish to empower the Chairman of a particular meeting to decide whether or not guests may attend that meeting'.

Mr R J Hook enquired whether the Chairman of a particular meeting would be placed in a difficult position at times.

The Chairman replied that this would often be the case. The Chairman of the meeting would consult with the Author(s) before making a decision. Since many guests wishing to attend a meeting made their applications only shortly before the meeting was due to take place, a decision was needed quickly. The Chairman of the meeting was best placed to make the decision.

Mr A H Syed asked whether guests meant guests from within the Society or included those from outside the Society.

The Chairman replied that guests normally meant those from within the Society, except perhaps on the occasion of a Guest Lecture.

Mr J C Harrison raised the question of the status of existing Associate Members who might not meet the Associations new criteria regarding technical qualifications. The Chairman replied that these were few in number and since they had been elected under the Rules existing at the time of their application, they would remain as Associate Members.

The meeting voted unanimously in favour of adopting the proposed revisions to the Rules.

Item 9

The Chairman requested the Honorary Secretary to advise the AGM on the election of Officers to the Committee.

President

Mr S N Clayton having completed one year in office had indicated that he did not wish to stand for re-election as President. Mr W H Marsden was nominated to succeed him. There were no other nominations and Mr Marsden was duly elected to the post of President. The Association wished to place on record their grateful thanks to Mr Clayton for all he has done for the Association during his term in office, and also to welcome Mr Marsden as the new President.

Vice-President

Mr W H Marsden's election as President left a vacancy for Vice-President, Mr D Rennie was nominated to succeed Mr Marsden. There were no other nominations and Mr Rennie was duly elected to the post of Vice-President. The Honorary Secretary welcomed Mr Rennie to the Committee on behalf of the Association.

Honorary Secretary

Mr S M Wehrle has now completed two years in office and is not eligible for re-election. Mr J J Goodwin was nominated to succeed Mr Wehrle. There were no other nominations and Mr Goodwin was duly elected to the position of Secretary. The Honorary Secretary thanked Mr Goodwin for his past assistance and wished him well in his new post.

Assistant Honorary Secretary

Mr Goodwin's election as Honorary Secretary left a vacancy for the position of Assistant Honorary Secretary. Mr J S Carlton was nominated to succeed Mr Goodwin. There were no other nominations, and Mr Carlton was therefore duly elected.

Honorary Treasurer

Mr D T Boltwood had completed two years in office and is therefore not eligible for re-election. Mr A A Wilson was nominated to succeed him. There were no other nominations, and therefore Mr Wilson was duly elected. On behalf of the Asssociation, the Honorary Secretary thanked Mr Boltwood for his many years of outstanding service to the Association, firstly as past Assistant Honorary Secretary, then Honorary Secretary and recently as Honorary Treasurer.

Honorary Auditors

Messrs Leighton and Mounch have served another year as Honorary Auditors and both were willing to continue as Honorary Auditors for a further year. The Association indicated that it was in favour of Messrs Leighton and Mounch continuing. The Honorary Secretary agreed to write accordingly.

Assistant Honorary Secretary for Corresponding Members

With the corresponding members taking a more active role in the activities of the Association, and especially in view of the anticipated increase in work load associated with the implementation of the awards scheme, the Committee wished to appoint another Assistant Honorary Secretary with responsibility for Corresponding Members. Mr N A Dawson had been nominated for this post. There were no other nominations and Mr Dawson was duly elected.

ITEM 10

The Honorary Secretary continued to the election of the Committee, and proposed the persons nominated to be elected 'en-bloc'.

Mr D T Boltwood	Dr Nataraja
Mr J W Fisher	Mr T Sullivan
Mr K J Fryer	Mr B P Thomas
Mr R M Hobson	Mr B Wilson
Mr J Lunt	Mr A C Wordsworth
Mr D McColville	

The above were duly elected.

As past President and past Honorary Secretary respectively, Mr Clayton and Mr Wehrle remain on the Committee ex-officio for a further year.

Concerning the Corresponding Members, taking account of the re-distribution referred to in Item 6 in the Agenda, the Honorary Secretary proposed the following persons nominated to be elected 'en-bloc'.

Corresponding Members

UK:

Hull	H Milne
Newcastle	E Whitehouse
Aberdeen	W F Rogerson
Glasgow	A R Morton
London	K J Fryer
Southampton	L O Christensen
Liverpool	J Nugent

COUNTRIES:

Canada	Montreal	C A C MacGregor
USA	New York	W E Tuck
Central America & Caribbean	Mexico City	—
South America	Rio de Janeiro	R de F Gomes
Scandinavia	Copenhagen	J G Lassen
	Gothenberg	K O L Nilsson
Netherlands	Rotterdam	C P Molenaar
Belgium & France	Antwerp	W J G De Backer
Central Europe	Hamburg	C M Bergmann
	Dusseldorf	—
Poland	Gdansk	J F Hills
Iberian Penin	Madrid	H Garcia
Italy	Genoa	E V Villa
Eastern Mediterranean	Piraeus	J J Stansfield
North Africa	Alexandria	—
Southern Africa	Durban	C A Timms
Middle East	Bahrain	—
India & Pakistan	Bombay	S V Ramchandani
Central Orient	Seoul	J N McKay
Southern Orient	Singapore	B H Wong
Japan	Yokohama	K Seki
	Osaka	K Miyoshi
	Sasebo	R Hashiguchi
Australasia	Sydney	F B Last

27 Corresponding Members and 4 vacancies at present.

Mr Hobson pointed out that Mr Fryer appeared both as a corresponding member and as a member of the Committee. This seemed to be an anomaly. The Chairman replied that the Committee would seek the views of the members at London Outport in order to find out whether or not they would like to nominate an alternative corresponding member in the future.

Notwithstanding this, the Corresponding Members, as listed above, were duly elected.

Item 11

At this point in the meeting, the retiring officers stepped down from office and Mr W H Marsden assumed the chair. Mr Marsden said:

'Firstly, I should like to thank Stephen Wehrle for his tremendous efforts in the position of Hon Secretary during the past two years and especially for his valuable assistance during my term as Vice-President.

In thanking you all for your support, I only hope I can continue with the same lead and enthusiasm which the past President has conveyed during his period of office.

Communications seem to be an area where, perhaps, we can place more emphasis in the coming year. To accomplish this I seek your assistance. We are all aware of the amount of in-house lectures, training schedules, IMO and IACS working groups, external inter-industry meetings, Euro-ACS, etc, where technical information within the Society is being discussed very frequently. We, therefore, may consider that, in these times, formal papers may not be the only means to advance technical knowledge. The discussion groups have always proved popular in the Association's programme. A short resume of the discussion by the panel and the contributors from the floor of the meeting will provide useful information for our overseas colleagues or perhaps they will be more encouraged to take part.

The more participants who can be involved in either Committees, Discussion Groups or Formal Meetings, the more response we should be able to get from the membership at large. Examples have already been suggested for improving communications, such as more short articles about the Association in a Society's Magazine; Senior Management should encourage discussion about the Association's aims during their visits abroad; Managers of Departments could advise the Secretary of details of Technical Papers given to external meetings and finally using the Minutes of this AGM as a circulating paper. All these examples would encourage participation and I hope the Committee's Members and Secretaries will persue them with increased vigour.

My new responsibilities must follow the aims of past Presidents in trying to improve the involvement of members. I have found from my experience that becoming involved can only result from having a role to play and this, I hope, will develop from active communications within the membership'.

Mr R J Hook congratulated Mr Marsden and looked forward to greater participation in the Association's transactions from Outport members. He remembered, some years ago, a symposium of papers had been arranged on the subject of Hull Construction. He asked whether a similar symposium could be considered on the subject of 'Aspects of Machinery Construction'. The Chairman agreed to refer this suggestion to the Sub-Committee on Technical Papers.

Item 12

The President stated that there was one item arising from the last meeting of the Committee concerning procedure and asked the Honorary Secretary to introduce it.

The Honorary Secretary stated that the Committee had considered the question 'What constitutes a majority on issues requiring a vote?'. The Committee had decided that it will abide by a simple majority at its Committee Meetings and the AGM.

The Honorary Secretary further explained that the matter arose from a member of the Committee who sought clarification. There had not been, to the Committee's knowledge any cause to apply a ruling on a voting matter in recent years. The Committee, at this time, merely wished to inform this AGM of its decision and place the decision on record.

There were no other items raised.

The meeting closed at 16·15 hours.

J. J. Goodwin, Hon. Secretary

LLOYD'S REGISTER TECHNICAL ASSOCIATION

Balance Sheet as at 31 March, 1982

1981 £			1982 £	1981 £			1982 £
	General Fund				Current Assets		
	Balance B/F	613.38		21.62	Cash at bank (Current A/C)	400.53	
				238.41	(Deposit A/C)	—	
				260.03		400.53	
	Less excess of expenditure over income	19.53		—	Cash in hand	5.58	
613.38			593.85	260.03			406.11
1,400.00	Loan from Lloyd's Register	1,400.00		23.75	Sundry Debtors		11.10
	Less repaid	250.00	1,150.00				
				1,729.60	Stock of ring binders in hand at cost		1,326.64
2,013.38			1,743.85	2,013.38			1,743.85

N.B. Stock has been valued at lower of cost or net realizable value.

Report of the Auditors to the Members

The above Balance Sheet and attached Income and Expenditure Account has been drawn up from the documents and vouchers of the Association and the explanations given by the Officers thereof. We have examined the Income and Expenditure Account and Balance Sheet and are satisfied that they show a true and fair view of the activities of the Association for the year ended 31 March, 1982.

D. Leighton, F.C.C.A.
M. Mounch, F.C.C.A.
} Joint Auditors

Income and Expenditure Account for year ended 31 March, 1982

	£	£
Sale of 219 Binders		405·35
Less cost of binders sold		402·96
Surplus on sales		2·39
Interest received from deposit account		11·08
Grant from Society		100·00
		113·47
Less: Expenditure		
Gratuities	80·00	
Entertainment	53·00	
		133·00
Excess of Expenditure over Income		19·53

Cash Budget for 1982/83 is as follows:

	£
Balance of cash 1.4.82	406
Grant from Society	100
	506
Less cost of entertaining, gratuities plus margin for contingencies	150
Estimated surplus	356

Note: 1. It is assumed that cost of postage will continue to be borne by the Society.

2. The volume of binder sales is unpredictable, therefore, no account of this has been taken in the above figures.

3. No account has been taken in respect of the refund of the Lloyd's Register loan.

D. Leighton, F.C.C.A.
M. Mounch, F.C.C.A.
Joint Auditors

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A. Bell.

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Lloyd's Register Technical Association

Discussion

on

Mr. R. Porter's Paper

NON-DESTRUCTIVE EXAMINATION IN THE SOCIETY

This Paper was Awarded the 1982-83 L.R.T.A. Medal

Paper No. 1. Session 1982-83

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. R. Porter's Paper

NON-DESTRUCTIVE EXAMINATION IN THE SOCIETY

DISCUSSION

(In Order of Presentation)

From Mr. N. P. White:

It gives me very much pleasure and I am sure you will wish to join me in offering congratulations to Mr. Porter on his paper, "Non-Destructive Examination in the Society".

It is the first time for several decades that a paper has been delivered on this subject. Such is its excellence I am sure it will be the definitive work for the next decade at least.

The application and scope of NDE techniques has increased enormously in recent years and undoubtedly will continue so to do. This is particularly so in the case of pressurised water reactors of the type proposed for Sizewell 'B' Nuclear Power Station, where access is limited once the reactor has gone critical.

This in turn has brought about the need to demonstrate to statutory bodies and clients, the surveyors' abilities in the NDE field and will lead to more and more surveyors sitting the SNT-TC-1A examination and qualifying as Level II Persons in the appropriate technique.

Looking at a defect in a longitudinal flange weld not considered worthy of non-destructive examination, brought home to me very forcibly the lesson that any material will fail in a brittle manner if a condition of restraint is present. In this case the weld defect, detectable by routine non-destructive examination methods, provides just such a restraint, which could trigger a brittle failure.

With this in mind coupled with the thought that greater use should be made of NDE, I thank you.

From Mr. G. P. Smedley:

In 1934, Mr. H. N. Pemberton presented a paper on "Welding" to the Technical Association. It was outstanding. Many of his observations on the survey of welded pressure vessels, engine bedplates and entablatures, and structures are still useful in the modern world. With reference to NDE, his paper contained sections on X and γ radiography, visual inspection, M.P.I. and a "stethoscope" and hammer test.

Later he gave another paper to the Association on the radiographic inspection of welds. It was a classic and proved invaluable to surveyors concerned with survey during construction of fusion welded pressure vessels. There have been few changes in the principles and standards of acceptance since that time.

Recently when I was in Japan, I looked at radiographs of welds in the hull structures of new ships under construction in several yards. The standards were equal to those of high quality pressure vessels. The Japan Institute of Standards had set the acceptance criteria and these were adhered to in all cases.

In this day and age of fracture mechanics estimates of critical crack sizes in welded structures, it is often forgotten that a principal function of NDE is to maintain good quality workmanship. This does not imply that trivial defects should be cut out because repair welds may not offer any real improvement.

The "stethoscope" examination was probably the first type of sonic test proposed for the detection of cracks. A weld was tapped with a light hammer and the response was listened to with the aid of a medical stethoscope. It was claimed that cracks could be detected but I can find no record of successful application. The technique cannot have survived for long because it was not referred to in early rules and codes for welded constructions.

I remember the introduction of ultrasonic testing in industry, over 30 years ago. Initial interest was the detection of cracks and detrimental segregates in steel forgings for alternator and turbine rotors. In about the early 1950's some rotors burst in service from these defects. Users demanded superior quality forgings proved by M.P.I. and U/S testing. By 1956 some rotors were so tested from the outer and bore surfaces. Disputes about acceptance were frequent following check inspections on delivery to the works of the machine builders. In some cases delayed cracking had occurred following despatch from the forge. In others the dispute arose from differences in techniques and the skills of operators at the two works. Sometimes disagreement was resolved by sectioning the forging for determination of the natures and sizes of the defects. If the alleged defects could not be found, the builder had to pay for the replacement forging.

The NDE of highly stressed forgings gave impetus to major developments in steelmaking and processing at the forge. Here NDE was invaluable for proving the benefits of superior methods of manufacture.

Some forges also made fusion welded pressure vessels. Inevitably U/S inspections were made on butt welds for information purposes. The information was often far worse than anticipated by the welding engineers. This was usually the case for welds in thick sections. The disclosure of significant defects increased the use of multi-run machine welding of the main butts. This system offered better control of quality and defects were often confined to single, small weld beads.

It is now recognised in ultrasonic testing of wrought steel or welds that the detection of defects is best at low frequencies. Advantage is taken of the beam spreading by diffraction. High frequencies are performed for size measurement because the less divergence of the beam enhances the resolution. Where high speed automatic or semi-automatic ultrasonic testing is applied to welds in tubes and pipes in modern production, it seems impossible to obtain the best of both worlds. Would Mr. Porter comment on the sensitivity of these techniques and the reliability in terms of defect acceptance? Do video recorders or printers really provide any useful quantitative data in these applications?

Reference is made in the paper to the PISC and other investigations concerning probability of defect detection, and accuracy of identification and size determination. In the main it was difficult to judge the stated results because all dimensions of defects were not quoted; where a range of sizes of planar defects was involved, was geometric similarity the main feature? When results are expressed in terms of probability, the reason for, say, the 0·3 or 0·6 level must be established from the investigation. A technique which offers greater chances of detection or accuracy, may mean that operators lack reasonable skill. What is to be done about identification of defects and size determination? If some operators are superior to others don't standards and training require a detailed review? Isn't this the lesson of manual versus automatic scans?

I agree with Mr. Porter about the adverse effect of compressive stress on defect detection. Many years ago I was involved in an investigation of cracks discovered in an alternator rotor. Test pieces containing typical cracks were prepared from the rotor body. Under a compressive stress of about 120 N/mm^2 the cracks were completely closed and could not be found by U/S inspection. This is about the same level at which a shrink fit is penetrated by a beam. There was no doubt that tensile stress rendered the cracks more readily detectable and improved the accuracy of sizing.

The surveyor in the field has to certify compliance of a pressure vessel, for example, with a national code. Some codes

impose tight acceptance criteria, also a planar defect of any size is cause for rejection. It appears that many codes impose requirements beyond the levels of the capabilities of U/S operators and techniques. The whole subject requires a complete rethink. Irrespective of the nature of the defects, realistic levels must be established below which any flaw is accepted outright. Beyond this level more clearly defined conditions of acceptance/rejection must be specified in simple terms. If need be, design stresses, material properties and weld procedures must be such as to tolerate the flaws which are acceptable to the standard. Far too much effort is being directed at R & D in U/S testing in the hope of satisfying tight code requirements.

From Mr. A. Smith:

The Society's Rules, whilst indicating those connections requiring particular attention, allow the surveyor some latitude in the matter of numbers of radiographs.

It is considered that this method is preferable to the rigid application of a formula which would tend to inhibit a surveyor's initiative, based on his knowledge of the builder's capabilities and quality control procedures.

Welding malpractice will not be rectified by a change in our system, indeed, the restraint placed upon a surveyor by a rigid number of check points may well encourage it.

In the matter of reporting, the First Entry reports for the different types of ships are inconsistent—some surveyors report solely the areas of examination, others add numbers of radiographs taken. The surveyor is not required to report—in the case of chemical tankers for example—that he has carried out the Rule requirement of N.D. Testing on, say, 10% of the cargo tank boundary welding. His reference to the areas of examination is sufficient.

What is considered of paramount importance is that the removal of a defect should be complete and not—as the Author states sometimes happens—a partial rectification. No rules can ensure that defects are completely removed and it is expected that the surveyor, having found a defect, should instruct the builders as to the extent of back gouging to be made. In many yards this is the standard practice of the quality control department but the author's reference to it indicates that this good practice is, by no means, universal.

From Mr. M. A. Fingalsen:

I would first like to thank Mr. Porter for an interesting and informative paper which I enjoyed very much.

Although I have no specific questions, I should like if I may, to add a few details regarding the ships mentioned in Section 4 on page 10 which suffered brittle fractures.

Three cases of brittle fracture are quoted, originating from gross defects in manual welds. Whilst it is correct that these defects would have been detected by NDE, it is important to recognise that the main cause of the failures was incorrect fabrication and erection procedures. I believe there were some special circumstances surrounding these vessels.

The first vessel, the Kurdistan, is illustrated in Figs. 7 and 8. As Mr. Porter says the weld defect was in a butt weld of the bilge keel flat bar. However, this was caused by an incorrect assembly and welding sequence during a damage repair in dry dock. After the new section of flat bar had been brought into place, the new section of bilge keel was lapped onto it prior to completing the butt weld in the flat bar. Consequently, the back run of butt weld in the flat bar, in way of the lap, was not carried out. The situation was made worse by the absence of an edge preparation, leading to incomplete penetration in the rest of the weld. This repair was carried out during a night shift and without the knowledge of the local surveyor.

Coming to the second ship shown in Fig. 9, I felt it was perhaps, inappropriate to introduce this as another weld not considered worthy of NDE. No opportunity for such consideration occurred in the case of the first ship, the Kurdistan.

In making the erection butt welds in the side longitudinals shown in Fig. 9, excess material had been left at the join. On trimming off this excess at the ship, the original edge penetration was damaged, resulting in gross defects buried in the weld. The situation was further aggravated by poor welding and incorrect welding sequence.

The third ship is not illustrated in this paper. However, the main manual weld concerned was in a butt weld in the deck of an oil tanker where a short section of defective deck plate had been replaced on the berth whilst building. This is certainly an area which should be considered worthy of NDE.

There was a later fracture, further forward in the deck which started from a butt weld in a save-all flat bar welded to the deck. This butt had only been welded from one side and so the defect should have been evident from a visual examination.

I would also like to make some comments on the last paragraph on page 10.

I was a little surprised at the references to an "apparently insignificant weld in the flat". This is a longitudinally continuous member attached to the main hull. The rules clearly require that the quality of welding and workmanship are to be equivalent to that of the main hull structure, including NDE as required by the surveyor. This requirement is given in Part 3, Chapter 10, Paragraph 5.4.1 of the Rules.

Reference is then made to the "flat ground-bar of the bilge keel". I believe this may lead to some confusion. The Rules refer to a bilge keel ground bar and envisage this welded tangentially to the shell like a doubler as shown in Part 3, Chapter 10, Figure 10.5.1 of the Rules. Other designs are also considered, such as that shown in Fig. 8 of this paper where a flat bar welded perpendicular to the shell is shown. This distinction between a bilge keel ground bar and flat bar is fully covered in Hull Structures Report 81/32 forwarded to all offices with Ship Letter 136.

From Mr. J. G. Lambie:

In Paragraph 4.13(a) the writer draws attention to the problem of lamellar tearing. It is agreed that the use of Z quality steel can help to minimise this problem but attention to detail design is of equal importance.

Bulkhead stool connections to the inner bottom at the bottom of bulkheads of large OBO ships and ballast holds bulkheads of large bulk carriers are areas where through thickness forces can be high these, however, can be reduced by making the stool as wide as possible. In the case referred to the stool was very narrow resulting in through thickness forces of a high order.

Many ships have been built since this incident with stools of the order of 3/4 metres wide and without incidence of lamellar tearing.

From Mr. R. M. Hobson:

Firstly I would like to offer my congratulations to the Author for a most illuminating paper on the state of the art so far as it relates to the most widely used principles of non-destructive examination used by the Society.

I would not take issue with the author at his choice of title except that he has strayed from the three most widely accepted forms of N.D.E. (Ultrasonic, Radiographic and Surface Crack Detection) to also refer to Acoustic Emission Testing in Section 5 of his paper. Surely not really a non-destructive examination because it relies upon failure of the structure to give an indication that all is not well.

Another acoustic test familiar to all marine engineer surveyors is the ringing test on bottom or top end bolts etc. This test is not referred to in the Society's Rules but the older Rule Books certainly contained instructions to perform such a test on cast steel anchors at the manufacturing stage. Even the minimum weight of the hammer to be used was stipulated!

Mr. Porter refers on page 1 of his paper to the 1934 Requirements for Welded Pressure Vessels and another test stipulated in the Rules until a few years ago was the requirement that the welded longitudinal seams should be well hammered whilst the vessel was under hydraulic test. I suppose that like the Acoustic Emission Test, the value of this exercise only became apparent if the structure failed the test!

I came across an interesting acoustic test during my service in Japan at the time when turbine driven tankers were being constructed and we were examining machinery plant steam condensers for tube end tightness. In this test the condensers were subjected to a very low internal pneumatic pressure and a sensitive microphone connected to an amplifier was passed over the tube ends to detect the hiss of escaping air.

This description naturally leads one to think of the humble soapy water test, practiced where suitable, on pressure vessels and pipe systems whilst under pneumatic pressure. Incidentally the addition of a little glycerine to the soap solution makes the liquid more effective and long lasting.

Similarly, the Halide lamp is used to detect the escape of refrigerant gas (R12 and R22) by a change in the luminosity of the flame.

In Section 4 of his paper the author refers to volumetric inspection methods such as ultrasonic testing and radiography. I must confess that I have not come across the term "volumetric" used in this sense before.

But there is a volumetric test which is particularly applicable to certain pressure vessels where an inner flexible envelope is reinforced by some outer containment system which precludes ready visual examination of the innermost membrane.

Coil wound reactors are an example, wherein the inner membrane is enclosed by band upon band of thin sheet steel to form an outer casing. (Those who are familiar with this form of construction will think my description very simplistic.) Anyway, the vessel is filled with water taking care to eliminate all air—indeed the water is heated to drive off dissolved gases so far as practicable. Next the vessel is pumped up to the hydraulic test pressure whilst carefully gauging the additional quantity of water introduced into the envelope. Now, provided that the pressure vessel has not deformed beyond the yield point of the material then an identical quantity of water will be exuded when the pressure is released. That at any rate is the rationale behind this test.

A comparable test, particularly applicable to pressure vessels of complex shape is the brittle laquer test wherein any excessive deformation of the structure shows up under hydraulic test by well defined crazing or cracking of the laquer.

The difficulty of such a test is in the matter of interpretation of course, and this is where strain gauging can give a quantitative assessment of the induced stress. Some of the examples of N.D.E. that I have quoted above are put forward rather with tongue in cheek but strain gauging at least merits inclusion in Mr. Porter's paper.

Perhaps the explanation lies in the title of the paper and one should not confuse *Examinations* with *Tests*. However, it is well to bear in mind that examinations are best carried out on components in a stressed condition wherever practicable.

Finally, the Author refers in Section 5 of his paper to recent developments in N.D.E. and rather implies that there have been no great advances in the last decade. This is possibly true, but an interesting development being applied in the medical field is the direct recording of X-ray images onto magnetic tape in the same manner as video cameras transfer visible light images onto magnetic tape. Subsequent viewing of the tape on a video display unit gives one an opportunity of readily altering the contrast or density of the image and the magnification of selected areas of the image can be altered as well.

I think it can be confidently predicted that this and other developments in medical electronics will benefit our own profession in the coming decade and give the author an opportunity to update his excellent paper.

From Mr. R. Liston:

Mr. Porter has presented an excellent paper on the four principal methods of NDE used in ship and machinery construction. These methods are used almost entirely after completion of fabrication and Fig. 9 prompts me to stress the equal importance of visual examination of joint preparations prior to welding. In this instance, the preparation was supposed to be a single vee with welding from one side only and it must have been obvious to everyone, including the welders, that it was physically impossible to obtain sound full penetration butts in the flanges of the longitudinals with the weld preparation actually used.

I would also like to comment on the Paragraph (4.1.3) dealing with 'Problem Areas'. The extent of NDE and weld defect acceptance criteria for ship construction is important and is, in fact, currently being considered by an IACS Working Party, but it will be some considerable time before there is any hope of a unified requirement being agreed.

The acceptance criteria at present specified in many codes for welded constructions tend to be very empirical and ignore one of the most important parameters, which is the defect height or through thickness dimension. This can only be determined by ultrasonic methods and I am pleased to note that Mr. Porter has given details of suitable procedures in Appendix II of his paper, although disappointed to hear that the accuracy is ± 1.5 mm.

The acceptance criteria must obviously vary with the position of the weld in the ship and there is possible merit in having two levels—one based on a fitness for purpose concept where defects must be repaired and the other for quality control and maintenance of general standards.

In Paragraph (c) 'Material Quality' I would disagree with the statement regarding problems caused by poor quality steel. It all depends what one means by 'quality.' This word is now generally used in a fitness for purpose sense—evaluation of a steel grade relative to its ability to satisfy a given need.

The old, very simple, requirements for ship steel were perfectly adequate when riveting was used as the method of construction, but problems arose with the introduction of welding. This required the development of notch tough steels —special steel grades.

Similarly, the possibility of lamellar tearing occurring in a welded structure had been recognized for many years and was avoided either by design detail or by the use of forgings or pipes. The incidence of this type of defect in ship construction is very low. The problem only came to prominence with offshore structures where tee-butts in thick plate material could not be avoided. As Mr. Porter remarks, Z-plate was developed and this should be regarded as a super grade.

To summarise, I suggest it would be fairer to classify steels as follows:

Grade A	—	standard quality
Grades B, D, E	—	special qualities
Z-plate	—	super quality

WRITTEN CONTRIBUTIONS

From Mr. W. H. Marsden: (Headquarters)

I am forwarding this written contribution to the above paper as, on the night, I was present in the capacity of Chairman of the meeting.

It was quite evident from the large attendance, that it was a subject which was both topical and interesting. I am grateful to the author for his paper and my comments are intended to complement his classical addition to the Technical Association records.

My remarks will only be addressed to the small part of the paper concerned with the marine application of N.D.E

Under the heading of criteria on page 12, perhaps we must ask, what is the purpose of N.D.E. in the Rules? First, we have to satisfy the Rule requirement that the welds are to be substantially free from slag inclusions, porosity, undercutting or other defects. Second, when dealing with terminology, when is a discontinuity in a weld considered to be a defect? This can be judged under two criteria by:—

1 The experienced surveyor.

2 A complex fracture mechanics calculations which will require to include experimental data to obtain a result.

A standard form of an acceptance criteria, used as guidance, could not fully take into account the changing stress pattern of the unsymmetrically and non-uniform structural arrangements on ships. On spherical tanks without stiffeners or girders perhaps a standard criterion of acceptance can be considered.

The progression from a weld discontinuity to a defect in practice can be due to the workmanship associated with the welded connections, welding procedure, access available for welding (i.e. inner surface of the butt weld joining the flange of the longitudinals) and also involves the efficiency of the welding plant and appliances, storage facilities for electrodes, proficiency of welders and their supervision, working conditions and weather.

Connections which are difficult to weld due to access, or involve complex welding procedures, are covered by the Rules and require sample joints to be prepared under conditions similar to those which would be obtained during the construction of the ship. An example of this would be when butt welding a thick flange of a longitudinal.

It seems logical to consider that, with the above large number of variables, the N.D.E. can be the best method available to ensure that workmanship is being maintained to the standard of shipbuilding practice as defined by the experienced surveyor.

Having now suggested that N.D.E. is being used to maintain workmanship and obtain welds which are substantially free of defects, the number of radiographs required must be decided by the surveyor and depends on the results of radiographs and the experience he has of the Yard's tolerances and welding capability.

The formula the Author suggested on page 12 could be used as a guide. However the repair rates, of above say 5% as a maximum, may raise a few eyebrows even in the Far East.

N.D.E. should be an ongoing technique to check on workmanship as the construction progresses. It can be performed more readily with an ultrasonic capability as part of the quality control checks of the Yard.

Unfortunately, we have on record a case of a ship which suffered a brittle fracture due to the over restricted attitude of quality control departments. They repaired only the parts that were defective without considering the resulting critical restraints over the length of the butt.

It has always been the practice to confine Rule requirements to essentials and to give surveyors scope to exercise professional judgement based on their experience. The answer for the shipyards would be to have a written definition of the Yard's own working standards including tolerances and the necessary correction methods which is enforced by an effective quality control staff. This must be a development of need which eventually would benefit the shipbuilder, by increase in production.

When examining new Yard Reports prepared by the surveyors, it has become the practice to request the following information for record purposes:—

1 Management structure available for fabrication and welding control during construction.

2 Quality control including N.D.E. available for maintaining workmanship and welding production standards in the Yard.

From Mr. O. M. Clemmetsen: (Newcastle)

Mr. Porter has given us a very thorough and extensive account of his subject which will be a useful reference for surveyors for many years to come, and will also form a useful introduction to those who take the N.D.T. Course at Crawley.

One of the items in the paper that somewhat alarmed me was the comparatively low capability of detection of defects by ultrasonics in various trials mentioned by Mr. Porter on page 3. This applies especially to cases where complex geometry is involved which instances are most likely to be found in pressure vessel situations and offshore constructions. The adverse effect of misalignment of more than 10° to the beam is also food for thought and shows the necessity of using various scanning methods with different probes.

Fortunately in ship construction most weld configurations are simple, while defects are unlikely to be isolated in the case of machine welds and therefore more easily detectable. However, manual welding on erection butts is another situation and here satisfactory welds need good fit up.

Much of the research on this subject seems to be in the pressure vessel field, with plates much thicker than are used in ship construction—could the author state whether detection of defects is improved with thinner plates?

One area in ship construction which has always caused numerous discussions in the Society, but has so far not resulted in firm recommendations, is the number of welds which require to be subject to N.D.E. I have a feeling that most shipyards in the U.K. building vessels exceeding 90 m in length would, in the normal course of events, exceed the number of radiographs determined by the formula on page 12, but in any case any formula which might be introduced should emphasize that the requirement is a minimum.

Perhaps the time is ripe to ascertain the actual practice in number of radiographs world wide especially in the distribution of radiographs over the length of the ship. The First Entry Report already requested a total number of radiographs to be recorded, but it is not specific as to their distribution. One could specify a certain percentage of the length of butts and seams with the midship $\frac{1}{2}$L to be examined.

The subject of N.D.E. is very strongly linked to the question of defect acceptability, and we seem to be a long way from firm recommendations on this aspect. I have often thought useful information might be obtained from N.D.E. of selected parts of old ships before being broken up—has the author any views on this matter?

Mr. Porter has given several useful hints to field surveyors in his paper which could be picked up with careful reading, and amongst these I would draw surveyors attention to page 3 paragraph (iii) in the left hand column, also the last two paragraphs under "Recording" on page 5, and paragraph (b) (ii) on "Limitations" in page 8 together with the last paragraph under "Falsification".

Finally, I would thank Mr. Porter for very kindly repeating his presentation for the benefit of Newcastle and Middlesbrough office—the large turn out fully justified the decision to ask L.R.T.A. to make the necessary arrangements for which we also thank them.

From Mr. K. O. L. Nilsson: (Gothenburg)

All outdoor surveyors are indebted to Mr. Porter for having presented this comprehensive paper of great interest which will no doubt serve as a handbook to surveyors all over the world in the years to come. It is important for surveyors judging X-ray films to have not only theoretical but also practical knowledge and at least some experience of handling X-ray equipment. Maybe I am right in assuming therefore that this paper will also serve as a text-book for coming N.D.E. courses at Crawley?

In the past surveyors from some countries having passed one of the courses at Ilford or Kodak could pass a test before a National Board and become authorised film viewers. The

author has presented some of the new international acceptance levels for operators in his paper. It would be interesting to hear his view on whether he thinks it possible for a surveyor having passed the N.D.E. courses at Crawley to fit into some of these existing schemes, or alternatively, if it would be of interest for the Society to have some kind of "graduation" inside the Society for authorised film viewers. I would go as far as saying that without proper knowledge in this field, it is impossible to act as a surveyor.

I think the author is a lot more pessimistic about the existence of weld defects in ships than I am. It is true that the number of films in new construction often covers less than 1 per cent of the total length, but proper shipyard procedure tests including destructive tests such as Charpy V tests in order to find out impact strength and ultrasonic examination in way of ends of automatic one or two run welds to trace hot cracks should eliminate systematic errors. The remaining occasional faults should be satisfactorily taken care of on a statistical basis by the shipyards recording all films against each single welder. To my mind the most important thing in order to avoid casualties such as those described in the paper, is not to increase the number of films but to ensure sufficient design knowledge or experience of people dealing with repair work during dry dockings. I am still considered a freak animal scrutinizing bilge keels and gunwale flatbars for cracks or otherwise defective welding. I often hear: "Why bother, it is only a thin flatbar welded to the deck." I am of the opinion that brittle fractures in ships can in most cases be avoided whilst still in the fatigue stage if properly looked after.

Having said this I cannot resist the temptation to show the photograph below indicating what may happen in the absence of N.D.E. The picture shows a buttweld in the face bar of a beam supporting a gantry crane. It had about 130 brothers, all of the same outstanding quality. Needless to say that the Society was not involved in the survey of this work, which took part in a country not to be revealed.

From Mr. E. Whitehouse: (Newcastle)

Mr. Porter is to be congratulated on the thorough way he has presented the many facets attached to non-destructive examination applicable to the work of the Society.

It is noted that it is now policy that all field surveyors will eventually attend a N.D.E. course followed by subsequent updating courses and it is felt that this paper is an ideal "crammer" for the surveyor attending such courses.

Mr. Porter rightly points out that it is essential that a surveyor requires to have a good working knowledge of the various N.D.E. methods available so that the evaluation obtained is a correct guide to the quality of the product and workmanship. This illustrates that careful and constant attention to inspection is very important and that one of the most important N.D.E. methods that can be applied is that of visual examination.

An obvious example of the latter is the examination of the fibreglass coatings on the portion of tailshafts which would otherwise be exposed to the effects of the sea water.

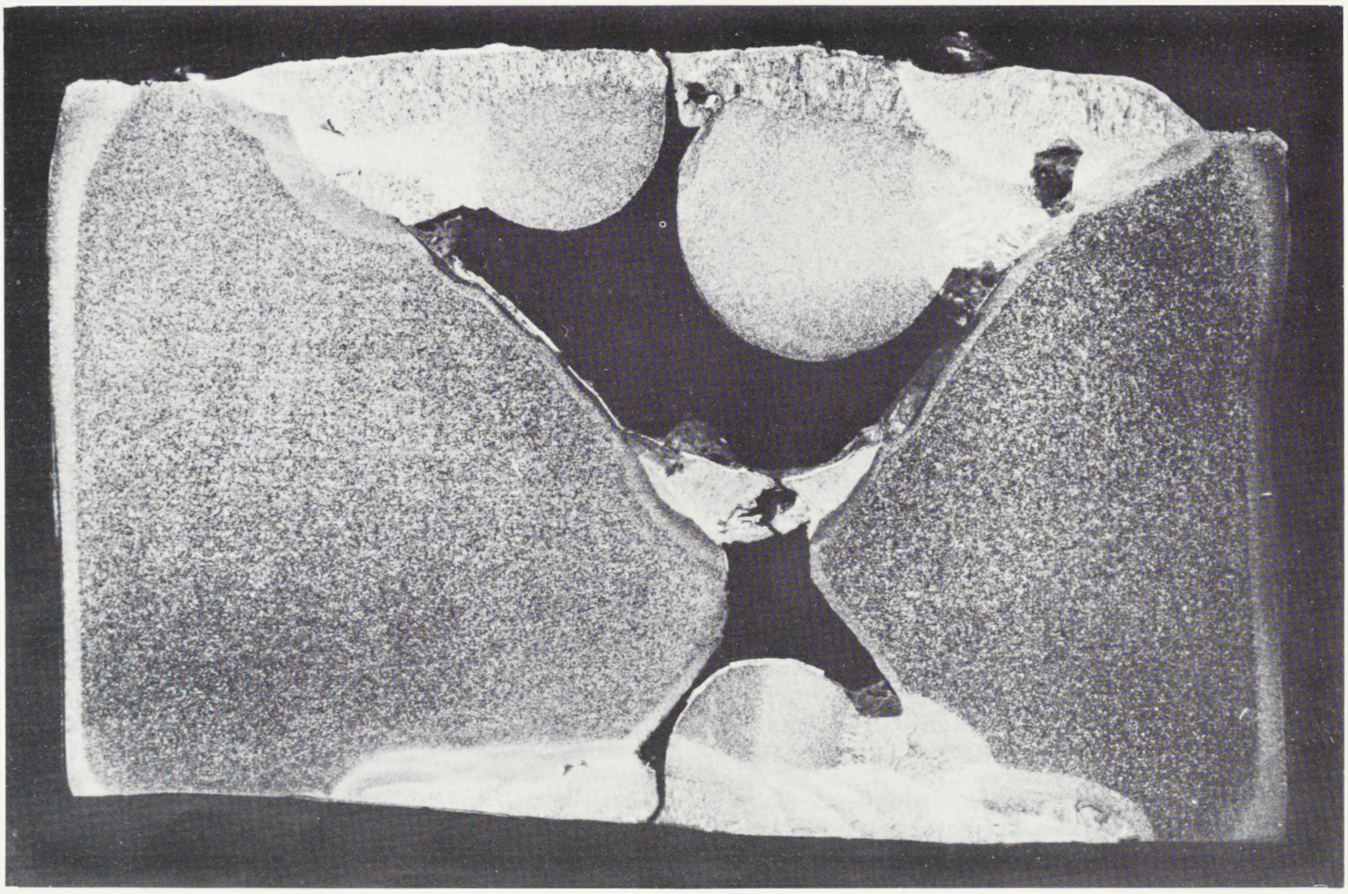
Could Mr. Porter suggest any other method of N.D.E. to check the integrity of these fibreglass coatings?

From Mr. J. C. Adam: (Headquarters)

Mr. Porter has given us a valuable review of the state of the art which will, no doubt, be used as a reference document for years to come.

In his discussion of the extent of N.D.E. to be applied to the structure of a ship's hull, he has offered a guideline as to current practice, and proposed a formula for the number of radiographs necessary.

Clearly, the extent of radiography necessary will vary according to situation and ship type (gas carriers have been mentioned), and any formula should be for a minimum requirement; the surveyor must retain a considerable degree of



freedom to use his judgement. The additional requirements for chemical tankers (Pt. 3, Ch. 10, 2.3.10. of the Rules) have not been mentioned.

From Mr. G. Dargle: (Headquarters)

With reference to Section 4.2, Paragraph 4.2.2. of the paper entitled 'Node Welds'.

Reference is made to the efficiency of the examination being reduced as a result of restricted access.

It is considered that an explanation be given as to the reason for the reduced efficiency.

I conclude this comment refers to the difficulty of interpretation as a result of the large number of skips required to cover the weld joint, when carrying out single sided ultrasonic testing of the K or Y connections.

(A problem which has caused concern to site surveyors and N.D.T. operators.)

Further your comment that "Single sided ultrasonic or magnetic examination of the crotch areas of some K or Y connections are so restricted by the weld root configuration that it may be prudent to build up these areas by welding as a matter of routine."

Would it be right to assume that this comment refers to the difficulty in interpreting the weld root condition and, therefore, additional weld reinforcement is required to maintain the theoretical weld leg length i.e. that which has been effectively covered by N.D.E?

From Mr. A. L. Jemmett: (Newcastle)

With reference to Radiography Paragraph 2.2.4.(c) Slag Detectability, it is interesting to note that under the conditions stated, an acceptable weld radiograph could be in fact masking weld defects.

Conversely, in some material, radiographs of welds indicate defects which are non-existent.

In certain high corrosion resistant stainless steels, radiographs of proven sound butt welds show continuous tram line shadows on the side walls at approximately half depth.

It is appreciated that X-ray defraction is probably the cause, but why should shadows appear on the radiographs, when all the material alloys are in solid solution.

From Mr. Y. Ito: (Osaka)

We would like to offer our congratulations to Mr. R. Porter on the presentation of his paper, which has given significant guidance in the basic method of Non-Destructive Examination.

We would like to raise the following points for further understanding:—

1. Radiography Film Density:

The Society's policy in respect of Film Density has been noted as follows:—

(a) The area under examination should have a Film Density of 2.0–3.0 when two kinds of films are used; Ultra-fine grain high contrast direct type and Fine grain high contrast direct type.
(Please refer to the Surveyor guidance note on Radiography, 6th March, 1967)

(b) Most standards and specifications on Film Density require a minimum Density of 2.0.
(Please refer to the Training Course Notes on Industrial Radiography, Chapter 2).

The above density of 2.0–3.0 has been considered to be a 'Marvellous Factor', by which best radiographic quality could be gained and also a reasonable radiographic examination could be carried out.

We would enquire of the author why he would adopt and substitute the ASME Code Section V, Article 2 for the 'Marvellous Factor'.

2. 'Area of Interest' and 'Area under Examination'.

When most standards or specifications require a Film Density of 2.0–3.0, it is understood that 'Area of Interest' and 'Area under Examination' mean Deposit (welding metal) only and do not include HAZ. However 'Area of Interest' and 'Area under Examination', used in some codes, means not only Deposit but also HAZ. This difference of the definitions regarding the above mentioned areas is one of argument-points between manufacturer and purchaser (sometimes ourselves) at radiography examination.

Could the author give some clear definition of 'Area under Examination' so as to avoid unnecessary troubles?

AUTHOR'S REPLY

I would like to thank all contributors for the interest shown in the paper and for the comments made.

The bulk of the discussion has centred on ship-building N.D.E., indicative perhaps of an area of concern to the Society's Ship Surveyors. Some of the replies made to the points raised may appear to be irregular coming from a specialist surveyor with little knowledge of ship building. In defence, the replies given are based largely on opinions expressed by many of the surveyors attending the Society's Training Courses in N.D.E.

The lack of comment made on the more advanced testing methods is ominous. Can it be inferred that non-destructive testing is moving out of the realm of the non-specialist surveyor?

To Mr. White:

I thank Mr. White for his comments. Possibly the most significant change in N.D.E during the last decade has been the implementation of formal N.D.E. procedures within quality control programmes. Procedures which insist on certificated personnel. The surveyors role has changed accordingly. Prior to effective quality control programmes the surveyor was accepted as an authority whose verdict on N.D.E. matters was final. Now the N.D.E. competence of the uncertificated surveyor is increasingly queried when an effective quality control has been established.

As Mr. White has suggested it is perhaps inevitable that the certification of surveyors in the basic N.D.E. methods will become widespread either by the expansion of the in-house SNT-TC-1A scheme or possibly by the imposition of external schemes. This does not infer that surveyors will be expected to use N.D.E. equipment. Any certification should be relevant to the surveyors duties, typically evaluation of radiographs or acceptance of N.D.E. reports.

It is of interest that some of Society's surveyors in Japan are qualified to the Japanese National N.D.E. scheme by external examination. Perhaps a general solution will be for selected surveyors to undergo more intensive N.D.E. tuition than that provided by the existing training course, this tuition to be followed by formal examination.

To Mr. Smedley:

I note the ability of Mr. Smedley to raise so many pertinent points, one in particular that cannot be re-stated too often—N.D.E. should be regarded as a part of a quality control programme and not as an entity. The mere imposition of N.D.E. has never instilled quality into a product. Unless production procedures are amended in the light of N.D.E. results, the benefits of the exercise are not realised. When faults such as incomplete penetration or porosity appear regularly on radiographs it is obvious that weld preparations or welding conditions have been unsatisfactory and that some corrective action is required. Hopefully, the recently issued Circular No. 2404 will prove to be a step in the right direction.

With regard to the automated ultrasonic examination of welded pipes and tubes the limitations of the method include those already mentioned in the paper. The selection of probe frequency is invariably made according to the thickness of the component, typically 5 MHz probes for thicknesses up to about 25 mm, 2 MHz probes for greater thicknesses. Results of trials published by the Welding Institute in 1979 (Reference 3 in the paper) showed no significant difference between 2 MHz and 4 MHz probes in the accuracy of sizing length and cross section size of linear weld defects. With regard to defect detection it has been found that when distance amplitude curves are applied, the difference in signal amplitude relative to the reference level is not significant for 2 MHz and 4 MHz probes provided the defects lie within the effective range of the higher frequency probe.

With regard to video recorders and printers the quantitative information presented by most systems is limited to an indication of defect length. Attempted indications of defect height by these basic systems have not been successful. Probably the greatest benefit derived from simple recording systems is in the increased confidence that the entire weld volume has actually been scanned. Unfortunately, the additional work imposed on the manual operators in the evaluation of reported indications has often led to the discard of these systems in shipyards and at offshore sites. The more sophisticated recording and printing systems applied to data obtained from inspections of components in nuclear reactors do give some advantage over the manual examinations particularly with regard to repeatability. Computer based techniques, such as Time of Flight and Synthetic Aperature Focussing, have shown marginal improvements in accuracy over manual sizing techniques.

The comment made by Mr. Smedley regarding the assessments of efficiency of ultrasonic testing highlight the problems faced in the analysis of the data obtained. Unless the programmes are carefully controlled factors such as experience of personnel, equipment variables and recording systems can distort the results. Regarding the PISC 1 exercise the defect detection probabilities quoted were referring to vertical planar defects of more than 10 mm height (DZ). The population of these defects in the PISC analysis is not great. It would appear that the few vertical planar defects in the testpieces with DZ values of between 10 mm and 20 mm had length dimensions, DY, ranging from 38 mm to 75 mm, according to results shown in PISC report No. 6. Any geometric similarities within this group of defects are unclear. The reasons for the wide variation in reported results for PISC 1 are uncertain, all teams were supposedly working to the ASME procedure yet enormous discrepancies in reported signal amplitudes for the same defects have been shown.

It is doubtful whether ultrasonic testing will ever be capable of the defect identification and sizing accuracy assumed by existing pressure vessel acceptance criteria. These criteria were developed for radiographic examinations and could only be achieved by X-radiography of relatively thin welds. No one should be under the impression that a single shot radiographic examination will reveal all cracks or non-fusions in a given length of weld. Mr. Smedley has answered this particular question in his final paragraph, the effort does appear to be in the wrong direction, pressure vessel codes should recognise the known limitations of the available N.D.E. methods. Additional training and more rigorous examinations of personnel will only solve a part of the problem, factors such as experience, practice and conscientiousness are important, but even a perfect ultrasonic operator can only work within the limitations of the method.

To Mr. Smith:

The first point made by Mr. Smith regarding the number of checkpoints required during ship construction is valid. It was not intended to suggest that a surveyor be restricted by an upper bound on the number of checkpoints--rather the intention was to suggest a means of imposing adequate control on any reluctant shipbuilder by nominating a lower bound. At present the shipbuilder can argue that the Society's rules do not specify a minimum number of radiographs and that any increase in costs will affect competitiveness. By stipulating a minimum requirement applicable to all shipbuilders the Society will be seen to be fair and the surveyors position within the yard will be strengthened.

It is apparent from a recently drafted Circular that a minimum number based on the formula

$$N = 0.008L^2$$

where **L** is the vessel length in metres, is to be applied. The proposal in Circular 2404 that the amount of radiography be increased should repair rates exceed 10% is in agreement with the principle expressed in 4.1.3. Having given further consideration to this problem two factors are apparent. One, is that without universal acceptance criteria the shipyard working to more severe acceptance criteria may be penalised. The second is that the temptation to falsify results of radiography will be increased when repair rates approach the critical level.

Mr. Smith's second point, incomplete repair of weld defects is a malpractice that has misled some surveyors. Only the diligence of the individual surveyor can identify and eliminate this problem.

To Mr. Fingalsen:

Since the paper was presented another case of fracture apparently resulting from defective manual welding has occurred. The ship in question was of recent construction and the case appeared to illustrate many of the points made in Section 4.1 of the paper. There were no special circumstances regarding this vessel.

Not all surveyors appreciate the Society's Rule Requirements regarding non-destructive examinations of butt welds in longitudinal framing. In some yards only a minute percentage of these welds has been radiographed.

Equally some people in shipbuilding and ship repair yards, not necessarily Surveyors, scorn the evidence of the Kurdistan. To these people butt welds in keel bars are most decidedly unworthy of N.D.E. Again not many of these welds appear to be radiographed or subjected to crack detection inspections during construction.

Regarding the terminology of bilge keel ground bars I must accept guidance from Mr. Fingalsen. At the same time I would like to point out that the photograph in Fig. 8, which may have clarified my intent, became transposed from starboard to port during printing.

To Mr. Lambie:

It is interesting to note that the problem of lamellar tearing at tank-top/bulkhead junctions has been corrected by improved design and selection of better material. It may also be a factor that some yards apply routine ultrasonic testing to these junctions. Whether the example shown in Fig. 10 was unique is a matter of some doubt. I believe that a failure illustrated on Fig. 5 in the second paper of the 1969-1970 session presented to

the Staff Association by Mr. O. Nilsson and attributed to 'slaggy parent material' was an earlier example of lamellar tearing. Perhaps there are other examples of lamellar tearing that have not been identified.

To Mr. Hobson:

Proponents of acoustic emission would argue that all loaded structures contain flaws that are growing, albeit imperceptibly. The objective of acoustic emission is to detect incipient cracks and to warn of impending failure. Since the acoustic emission method itself is not responsible for the failure of a structure it is reasonable to include A.E.T. in the N.D.E. methods.

Mr. Hobson has mentioned some of the leak detection methods witnessed by the surveyors that are also within the scope of N.D.E. The reason for neglecting these methods in the paper was simply lack of space. With regard to other methods of N.D.E. mentioned by Mr. Hobson such as strain gauging and brittle lacquer coating these subjects have been discussed in presentation to the Technical Association by A. C. Wordsworth and A. J. Cogman.

The topic of radiographic image enhancement was actually included in the original draft of the paper but was deleted due to the limited relevance of the technique. The point about image enhancement is that such techniques are only worthwhile when the ultimate sensitivity has been achieved within the existing method. If increased radiographic sensitivity is desired it is better to use the finest grain size film available with the smallest focal spot size and greatest focus film distance commensurate with a reasonable exposure time. Only when such factors have been exhausted is it sensible to consider image enhancement. Having said this Mr. Hobson is undoubtedly correct, eventually the advances made in medical radiography and even more so in ultrasonics must be carried over to the industrial sector, at least for some applications—quite how one would carry out a Computerised Axial Tomograph, C.A.T., of a pressure vessel is not readily apparent. Medical practioners have three distinct advantages over the industrial world, one is that the value of a patient outweighs the value of a weld or casting and may justify the cost of the equipment, the second is that disparities between various human beings are less extensive than those observed in the various product forms and materials subjected to industrial N.D.E., the third is that human beings are more easily irradiated than solid metal components. An interesting article on industrial applications of C.A.T. has been published in the May 1983 edition of Materials Evaluation.

To Mr. Liston:

Mr. Liston reiterates an important point, the surveyor is expected to verify that weld joint preparations are adequate prior to welding. Whilst it is impossible to check every welded joint it should be possible for a surveyor to identify persistent or systematic malpractices. One of the main benefits of N.D.E. is to assist in the identification of these situations.

The thorny problem of acceptance criteria for welds in ships is one that has appeared on previous occasions in LRTA papers. The criteria applied to the majority of the merchant ships constructed today in Japan and S. Korea are based on Japanese Industrial Standard JIS Z 3104. Whilst empirical, the criteria are so strict that it is unlikely that any defect with a significant through thickness extent would be tolerated. For example, JIS Z 3104 will not accept any planar defects such as cracks, lack of fusion or incomplete penetration. The longest slag inclusion accepted must not exceed a value equal to half the plate thickness.

In view of the empirical nature of acceptance criteria the prime purpose of shipyard N.D.E. must be to assist in Quality Control. If all yards were to implement quality control to the extent practised by those yards mentioned in Mr. Smedley's contribution the question of fitness for purpose criteria might become academic.

To Mr. Marsden:

If the points made by Mr. Marsden are taken together with Circular No. 2404 the ship surveyors will have the essential information required for a satisfactory control system for shipyard radiography.

A valid point raised by Mr. Marsden after the discussion was that many shipyards already operate excellent quality control programmes. Whilst a few eyebrows might have been raised in these yards at the suggested 5% repair rate trigger for increased N.D.E. a few more eyebrows might be raised at the repair rates regarded as normal in other yards. The recently nominated 10% trigger in Circular No. 2404 would appear to represent a reasonable compromise. However, two other points now require consideration. Firstly, there will be an even greater incentive for the unscrupulous yard to deceive the Surveyor in the manner suggested in 4.1.3(d). Secondly, the yard working to a high standard such as that imposed by Japanese Industrial Standard Z 3104 will be penalised with respect to the yard that has no formal acceptance criteria and is prepared to tolerate more generous quantities of weld defects. Less experienced surveyors working in these latter yards might find the International Institute of Welding collection of reference weld radiographs useful material for guidance purposes. The 'blue box' edition of this collection shows five levels of weld quality, namely black, blue, green, brown and red in order of decreasing quality. Various examples of the different weld defects are shown in the collection. The practice in some European yards has been to accept radiographs graded as black or blue; to reject those radiographs graded as brown or red and to discuss those graded as green with the surveyor. Since the more significant defects such as lack of fusion or cracks are graded brown/red or red respectively, the surveyor is able to exercise his judgement on the amounts of slag, porosity, undercut and incomplete penetration to be tolerated at a particular weld location. Most surveyors would reject even the short lengths of incomplete penetration graded as green.

To Mr. Clemmetsen:

It is only in recent years that the limitations of ultrasonic testing have been analysed in detail and in public. When comparing ultrasonics with radiography it will be no consolation to Mr. Clemmetsen that radiography is probably even less successful in terms of overall defect detection. For the radiographic method, defect detection probability does increase as plate thickness decreases. With ultrasonics this is not the case. For thicknesses of less than approximately 25 mm radiography would be the preferred method, above 40 mm ultrasonics is preferred. Regarding defect acceptability, analysis of weld quality at the breaker's yard would probably complicate an already complex situation. Cases are known where highly stressed welds have survived despite the presence of conventionally unacceptable defects. The question to be posed is, how many such cases would outweigh one casualty arising from a similar condition? Since this question is unlikely to be answered the shipyards will be saddled with acceptance criteria based on quality control rather than on any fitness for purpose requirements.

To Mr. Nilsson:

Before replying to Mr. Nilsson's comments I feel that I must acknowledge Mr. Nilsson's contribution to the 1969-70 session of the Technical Association. In his paper references were made to the evaluation of radiographs in Swedish shipyards. Perhaps these references were a tactful hint to other surveyors that the I.I.W. collection of reference radiographs could be used to establish acceptance criteria.

It is apparent from Mr. Nilsson's comments that he has worked in yards where quality control is well established. N.D.E. surveyors on the other hand tend to become involved with the products of less well ordered yards. The true position

of ship weld quality presumably lies between our two viewpoints.

The question of certification of surveyors in N.D.E. methods has been mentioned in the reply to Mr. N. P. White.

For some years there has been disquiet regarding the absence of certification for surveyors evaluating results when formal certification has been a requirement for those producing the results. Examinations of selected surveyors to Level II, SNT-TC-1A have been carried out for some years, notably for surveyors working in Spain and South Africa. A feature of SNT-TC-1A is that specific examinations are included that relate directly to the duties of the surveyors.

It appears likely that more surveyors will become formally qualified in N.D.E. methods including visual inspection of welds. This is particularly so for surveyors involved in Offshore or Industrial Services work. A recent addition to the Crawley N.D.E. courses has been the formal assessment of ability in interpretation of radiographs. The assessments have generated a certain amount of discussion, not all of which has been favourable.

The photograph of the 'weld' cross section submitted by Mr. Nilsson would take any prize for the most callous disregard of basic safety.

To Mr. Whitehouse:

A method that may be useful for assessment of integrity of fibreglass coatings on steel tailshafts is the Holiday detection method. The method consists of rotating the component with the fibreglass insulator in contact with flexible conductors. Any gap in the insulator would be revealed by a high voltage discharge through the gap in the insulation. Portable instruments using either AC or DC supply are also available.

To Mr. Adam:

The point made by Mr. Adam has been covered in the reply to Mr. Smith.

To Mr. Dargle:

The reasons for the reduced efficiency of the ultrasonic scan shown in Fig. 12 are as follows:—

(a) In general, defects will only produce signals in excess of reference levels when the defect has a reflecting surface whose plane is within $\pm$ 10° of the beam angle. Not all of the fusion planes will be aligned with respect to a given beam at any one point around the rapidly changing weld profile in this area.

(b) Beam scattering and divergence will be increased by bouncing off the inner curved surface of the tubular. The origin of a reflected signal will be difficult to identify.

(c) The profile of the inner corner is usually unknown at the time of the ultrasonic examination, likewise, the root gap is usually unknown. Without precise knowledge of configuration weld root evaluation is impossible by ultrasonic methods. Ideally, profiles would be recorded at the fit-up stage. In practice this seldom occurs.

Mr. Dargle is correct in his assumptions. Due to lack of evaluation of weld root it becomes advisable to provide additional weld reinforcement to maintain theoretical weld leg lengths.

To Mr. Jemmett:

The phenomenon of diffraction mottling on radiographs of austenitic welds has been discussed by Dr. R. Halmshaw in the March 1983 edition of the journal of the British Institute of N.D.T. My own limited understanding of the subject is that when the wavelength of radiation, incident angle of radiation and spacing of atomic planes within a crystal have a specific relationship, diffraction will occur giving constructive interference within the radiation beam. The atomic spacing within austentic welds is more liable to produce diffraction than is the atomic spacing within ferritic welds. On manual austenitic welds in thin materials the diffraction may take a characteristic herring bone pattern. On thicker materials, particularly those made by automatic welding processes, the more regular crystal structure produces dark linear indications generally at the side wall of the weld.

No doubt a physical metallurgist could prepare a comprehensive paper on this subject. In practice the problem is overcome by one of three methods. Usually a change in wavelength of radiation will suffice. This is achieved by change in kilo-voltage or by switching from X to gamma radiation. Alternatively the incident angle of the radiation may be adjusted or the object to film distance may be increased. Neither of the latter solutions is advised since genuine defect indications may be lost by change of angle or by loss of definition due to increased object to film distance.

To Mr. Ito:

As Mr. Ito observes the Society's guidance notes on radiography nominate a minimum film density of 2.0 whereas the ASME Code, Section V, Article 2 will accept a density of 1.8 on X-radiographs. It is doubtful whether any significant difference in defect detectability will be discernible between radiographs of those densities taken under similar conditions. As a general rule a minimum density of 2.0 would represent good practice but in view of the widespread application of the ASME Code, surveyors should be aware that this Code will tolerate a minimum density of 1.8 for X-rays whilst requiring 2.0 for gamma-rays.

With regard to "Area of Interest" and "Area under Examination" the heat affected zone of welds must be included within this region. The problem of density difference between weld and HAZ is greatest when thin welds with reinforcement are subjected to X-ray examination. Since the film density will be lower at the weld it is the weld area that must meet the minimum requirement and the HAZ that must conform to any maximum limit.

For critical components the problem is overcome by grinding the weld flush. For less critical components shorter wavelength radiation can be used with consequent loss of contrast. Alternatively, cassettes can be double loaded with two speeds of film.

Rules for individual projects can only be defined by reference to the relevant code or specification agreed by manufacturer, purchaser and inspection authority. For routine shipyard work most surveyors would exercise some tolerance and aim for a reasonable density (greater than 1.8) in the weld area.

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FIRE PROTECTION, DETECTION AND EXTINCTION IN OFFSHORE INSTALLATIONS

G. Coggon & C. M. Magill

Paper No. 2. Session 1982–83

Hon. Sec. J. J. Goodwin
71 Fenchurch Street, London, EC3M 4BS

FIRE PROTECTION, DETECTION AND EXTINCTION IN OFFSHORE INSTALLATIONS

by G. Coggon & C. M. Magill

SYNOPSIS

The Society's involvement in fixed and mobile offshore installations has been steadily increasing during the last decade. In order to provide protection against the greater fire risks where mineral hydrocarbons are present on offshore installations it has been necessary to adapt both established marine practices and land-based petro-chemical industry's requirements to meet the special circumstances involved.

In addition to the Society's Rules for the Construction and Classification of Mobile Offshore Units the paper discusses the degree of authorisation given to the Society by the Administrations responsible for the exploration and exploitation of offshore mineral resources, the position adopted by IMO and the regulations with which compliance is required in each case. Explanatory comment on the basic objectives and essential features required for compliance with the regulations concerning the suitability and arrangement of materials and equipment for structural fire protection, fire and gas detection systems and fixed fire extinguishing systems is given. A section is also included concerning the fire aspects of offshore-related diving systems and specialist vessels such as fire-fighting units.

It is the intention that the paper will provide Surveyors with the information and guidance such that plan approval, as dealt with in Head Office, and surveys in the field will be easier accomplished thus improving the service to the Society's Clients.

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1. INTRODUCTION

Space limitations on offshore installations inevitably necessitate the close proximity in three dimensions of a number of hazardous process systems, utilities and transportation facilities which would not be accepted in similar land based installations either with respect to each other or to living quarters. Added to this is the limitation in the external assistance facilities which would be readily available ashore. Thus the nature of having offshore installations designed for drilling for and the processing of mineral hydrocarbons requires the fire protection system to be comprehensive.

These factors have to be taken into account so far as practicable by the segregation of hazards from each other, and from the living quarters, by the isolation of certain enclosed spaces by fire-resistant walls and decks, by the provision of gas and fire detection systems and by the selection and location of fire extinguishing systems and media most suited to use in a self-contained marine environment; this requires to be more comprehensive than is generally required for ships.

The basic principles which comprise the design philosophy for such a fire protection system are as follows:

(a) The division of the installation into vertical and horizontal zones by structural and thermal boundaries to segregate drilling, production process and utility areas from each other.

(b) The separation of the living quarters from the remainder of the installation by structural and thermal boundaries.

(c) The restricted use of combustible materials.

(d) The minimisation of accumulations of flammable vapours by adequate ventilation.

(e) The minimisation of the possibility of ignition of flammable vapours.

(f) The detection of flammable gas and fire in the zones of origin and initiation of the appropriate executive action.

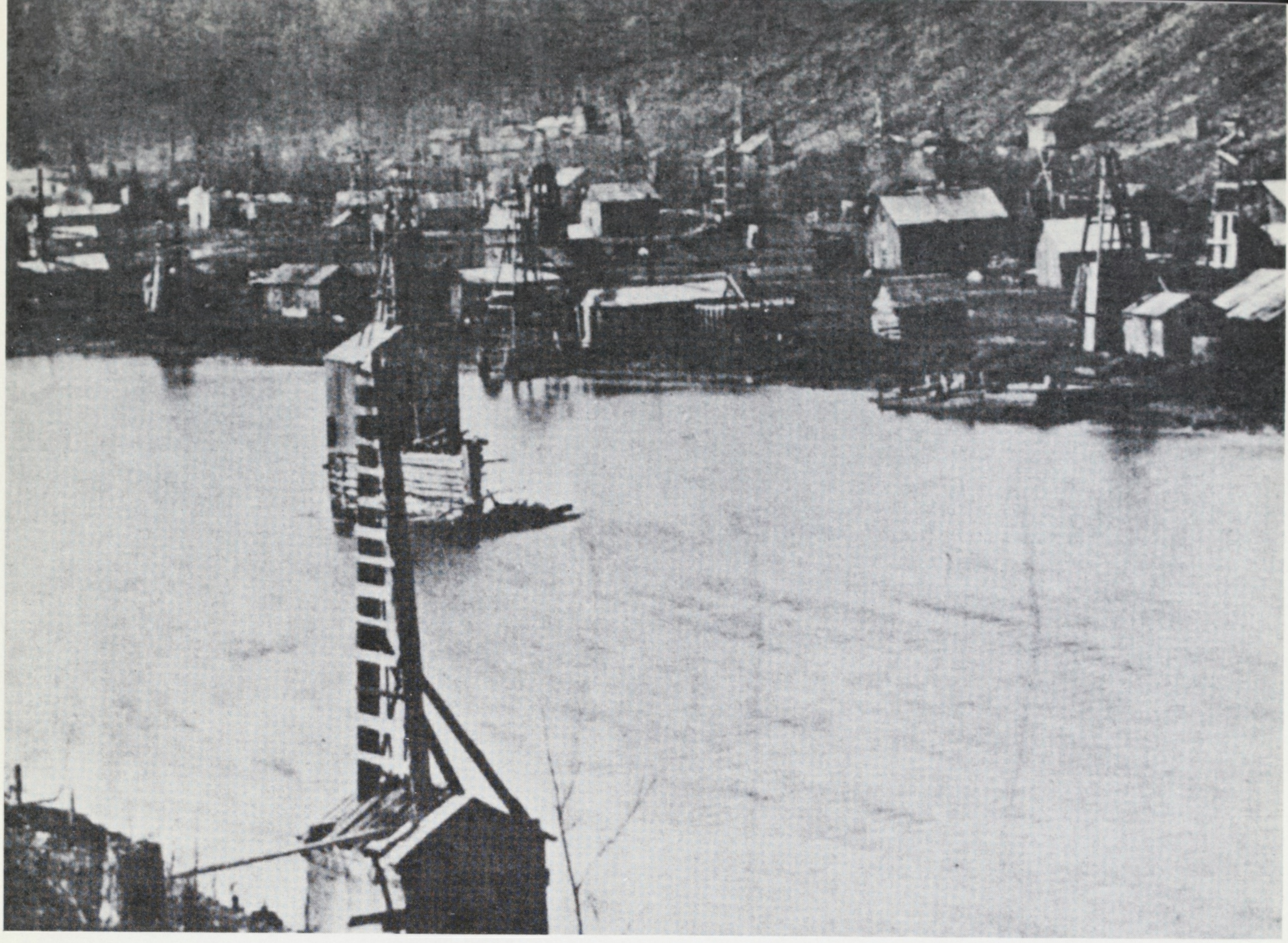
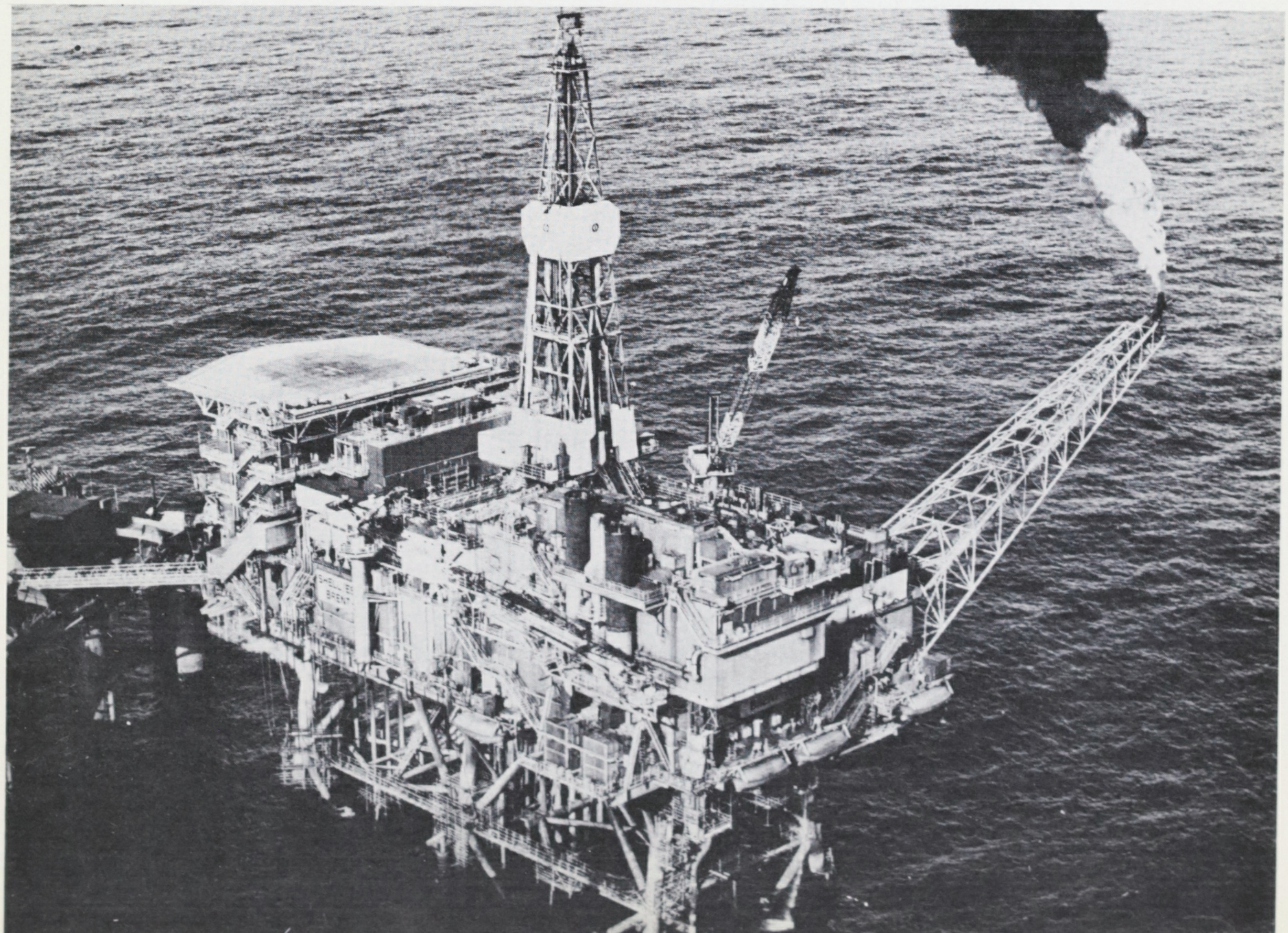


PLATE 1

Oil Creek, Pennsylvania, 1863—early offshore operations.

PLATE 2

Present day steel jacket platform, Shell/Esso Brent A.



(g) The containment, by means of fire divisions, and control of the fire in the space of origin by readily available fire extinguishing media.

(h) The protection of the means of escape or access for fire-fighting.

The risk of fire exists in all areas of an offshore installation to a greater or lesser degree depending on the equipment or materials likely to be found in each area. Equipment and pipework associated with drilling and processing of mineral hydrocarbons give rise to the possible risk of development of a dangerous atmosphere and a fire or explosion in the event of ignition. Thus, in addition to the provision of fire resistant divisions, to achieve the principles outlined in (d), (e) and (f) above, it is necessary to define and categorise the 'hazardous zones' where such flammable vapours could occur and take appropriate measures to preclude ignition. Examination of Builders' proposals concerning hazardous zones and the suitability of equipment for its location is carried out by the Society's Mechanical and Electrical Engineering Departments. These aspects have not been included in this paper which addresses itself only to the work of the Safety Section of ICD, namely (a), (b), (c), (f), (g) and (h).

The degree of involvement by the Society in ensuring that these aspects of design and construction are subjected to critical scrutiny is dependent on the intended location of a fixed installation or the area of operation of a mobile installation and can conveniently be separated into three categories;

1. Fixed and mobile installations established or maintained in the U.K. waters (commonly referred to as the U.K. Sector of the Continental Shelf).
2. Fixed installations established in areas outside U.K. waters.
3. Mobile installations operating in areas outside U.K. waters.

The Society has rules for mobile offshore units (in draft form at the time of writing) and the fire safety requirements set out there incorporate those of the IMO MODU Code and the relevant IACS Unified Requirements.

In some cases, such as units intended for operation in the U.K. sector of the North Sea, national requirements may be more onerous and would have to be complied with additionally as indicated in the appropriate sections which follow.

Unlike ships, mobile offshore installations are required to comply with the requirements of the country in whose waters they operate, in addition to those of the country of registration.

At present the Society has no published rules for the classification of fixed offshore installations and current practice in this respect generally follows the U.K. requirements.

2. FIXED AND MOBILE INSTALLATIONS IN U.K. WATERS

2.1 Certification Scheme

The Society has been authorised by the U.K. Administration to act as a Certifying Authority (C.A.) to: 'examine the design and construction for compliance with the Offshore Installations (Construction and Survey) Regulations 1974, Statutory Instrument No. 289, and to issue Certificates of Fitness (C.O.F.) for the purposes specified therein when satisfied that it is proper to do so'.

The installations covered by the scheme have been defined as 'all installations that may be manned, including mobile and fixed drilling and production installations, accommodation units, oil storage units, loading units, flare stacks, manifold and booster units on pipelines and any other type of installation which is directly concerned with exploration for, exploitation of or the conveyance by pipeline of petroleum products'.

It is important to note that the Certification Scheme is applicable to all mobile offshore units, regardless of Flag, whilst operating in U.K. waters.

The certification scheme does not cover dredging installations registered as vessels, installations capable of operating wholly submerged, crane barges, pipe-laying craft, service and stand-by vessels, and similar units whose function is directly associated with construction, service, safety, etc. rather than exploration or exploitation. At present mobile accommodation units (floatels) not intended for permanent use at any one site are exempt from C.O.F. requirements although it is understood that regulations are now being drafted for these units.

The fire aspects of the certification scheme are restricted to:

1. Structural fire protection.
2. Suitability of constituent materials with respect to fire hazards.
3. Escape routes.

2.2 Structural Fire Protection

Materials required to provide structural fire protection should comply with the requirements of a relevant code or standard. The materials and their method of assembly should be tested at a recognised independent establishment. The definitions concerning the SOLAS Standard Fire Test, non-combustibility, A-Class fire-resisting and B-Class fire retarding divisions have already been given to the Association in Paper No. 1, Session 1974–75; Fire Protection, Detection and Extinction in Ships, the comments of which remain applicable to the Regulation requirements concerning offshore installations.

In addition to the above, the document published by the Department of Energy (D.En)—Offshore Installations: Guidance on Design and Construction—also gives ASTM:E119-76 and BS 476, 'Fire Tests on Building Materials and Structures', as acceptable standards in assessing the fire properties of divisions. The test curve of time/temperature relationship in each case is approximately the same as that defined by the SOLAS Regulations. However in BS 476 and ASTM:E119-76 the presentation of the test results is different, the salient point being that assessment of the integrity and temperature rise is given as the time elapsed from the start of the test until specimen failure, whereas the SOLAS assessment gives a classification dependent upon the minimum time the specimen is required to meet the requirements for integrity and temperature rise e.g. A-60 Class, not less than 60 minutes.

The Society has found the BS 476 presentation of results useful in certifying fire divisions where the manufacturer of the division is building to an Owner's specification that the division should meet the integrity and temperature rise criteria for a period exceeding 60 minutes, usually 120 minutes, although tests have been carried out over periods up to 12 hours. Certification is given in the form of a factual Report 10 and includes a statement of the maximum SOLAS classification of the division. A typical certificate is shown in Fig. 1. Associated with this extended test period is sometimes a requirement to use a time/temperature relationship thought to be more representative of a hydrocarbon fire than that established for the Standard Fire test for a carbonaceous fire. The time/temperature relationship commonly used is known as the Mobil Hydrocarbon Curve and is shown superimposed on the Standard Fire Test and NPD curve in Fig. 2.

Whilst fire-resisting divisions of enhanced properties are often incorporated in offshore installations it should be kept in mind that the Regulations presently only require a maximum of A-60 Class.

By definition, a SOLAS A-Class division is required to have a structural steel core of not less than 4 to 5 mm thickness, whereas fire-resisting divisions complying with BS 476 may be 'load bearing' or 'non-load bearing' constructions, neither requiring a structural steel core. It has thus been possible to

Lloyd's Register of Shipping

71 Fenchurch Street, London, EC3M 4BS

Certificate No: ICD/F82/500

Date: 3rd November 1982

ITEM: FIRE RESISTING NON-LOAD BEARING PROFILED
STEEL CLADDING PANEL SYSTEM

MANUFACTURER: A. MODULE CONSTRUCTION CO. LTD.

This is to certify that the cladding system construction of 2.0 mm thick stainless steel plate profiled, reinforced and insulated with three separate layers of insulation comprising of ceramic fibre, calcium silicate based board and mineral wool, in addition two layers of ceramic fibre in the troughs of the corrugations, and having an overall thickness of 163 mm, the constituent materials and construction as detailed in the Warrington Research Centre Report W.R.C.S.I. No. 29329 dated 23rd November 1981, has been subjected to a simulated hydrocarbon fire test, the time/temperature curve sometimes referred to as the Mobil hydrocarbon curve, the conditions being more severe than the Standard Fire Test.

The bulkhead satisfactorily prevented the passage of smoke and flame during the test and when assessed against the performance criteria, given in both British Standard 476 : Part 8 : 1972, and International Standard ISO 834 : 1975, satisfied the requirements as follows :-

Stability	:	120 minutes (Test discontinued)
Integrity	:	106 minutes
Insulation	:	112 minutes

For the performance criteria given in SOLAS '74 the fire resistance was equivalent to that required for A-60 insulation rating.

The above stainless steel cladding system is acceptable for use as a non-combustible non-load bearing fire resisting division with these ratings in a vertical position in :-

(i) Offshore Installations subject to the Society's Classification Rules;

(ii) Offshore Installations for which this Society is authorised to issue Certificates of Fitness, and similar licences, permits, etc.

The above cladding system may be constructed of mild or stainless steel in thicknesses from 2.00 mm to 8.00 mm inclusive.

Note: This Certificate is valid for five years from the date of issue.

Deputy Chairman

pro Secretary

Fig. 1

Typical certificate of general approval for fire resisting offshore panel systems

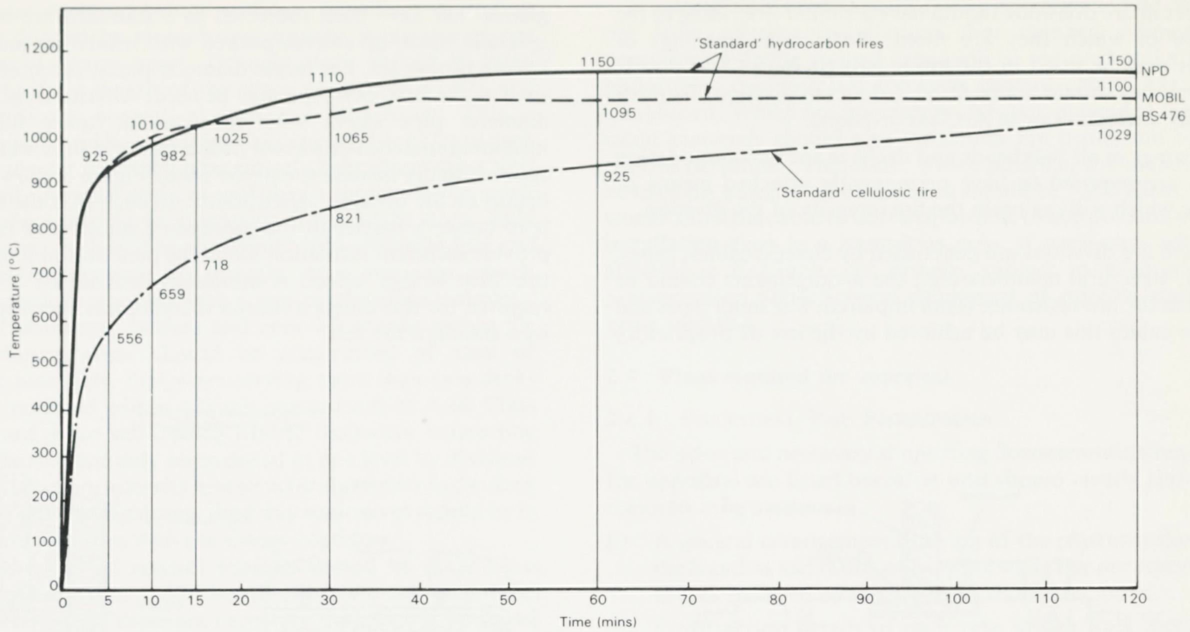


Fig. 2

Time-temperature relationships for standard fire tests

accept constructions for offshore use as 'non-load bearing panel systems' supported by structural steel frames where these have been demonstrated to satisfy the required integrity and temperature rise criteria. Such panel systems commonly consist of an external lightweight profiled steel panel covered internally by a matrix of thermal insulation and an internal aesthetic lining. They are mostly used in the construction of container type units employed for accommodation spaces, offices etc., and for the external boundaries of large accommodation modules. Their use in the working areas of offshore installations is restricted by the possibility of mechanical damage to the lightweight construction rather than from fire aspects.

All materials are to be non-combustible except that consideration may be given to the use of combustible material where it is demonstrated that any other required property precludes the material from being non-combustible. Materials such as organic foam insulation, e.g. polyurethane, which are combustible and also may give off large quantities of toxic fumes or smoke should not be used. However, such material is by far the best insulant for use in cold stores and refrigerated spaces and consequently such foam insulation for these spaces may be accepted provided:

(i) the foam is of a fire retardant type;

(ii) the foam is totally enclosed in stainless steel or other corrosion resistant material having all joints suitably sealed, e.g. welded or brazed;

(iii) the insulation and its casing do not form any part of the accommodation structure, i.e. decks, bulkheads, etc.

(iv) a suitable entry is made in the Operations Manual regarding the fitting and position of this insulation and precautions to be taken during any repairs.

2.3 Regulation Requirements

The definitions relevant to certain spaces whose boundaries will require fire protection are:

Control Stations: spaces in which the radio, main navigating, central fire detection or control, the installation central internal communication equipment, the emergency source of power or the emergency switchboard are located.

Accommodation spaces: spaces used for dining rooms, recreation rooms and similar permanently enclosed spaces including corridors, lavatories, cabins, offices, sick-bays, living quarters, pantries, lockers and all similar spaces.

The purpose of the remaining spaces requiring fire protection is self-evident from their titles.

In accommodation spaces each deck and its supporting structure, except where required to be constructed to A-60 Class, should be constructed of material which by itself or due to the insulation provided will not lose its structural stability or fire integrity when subjected to a 60 minute standard fire test. In practice this means, that due to the mechanical loading a deck is expected to withstand, the fire rating is generally of A-0 Class.

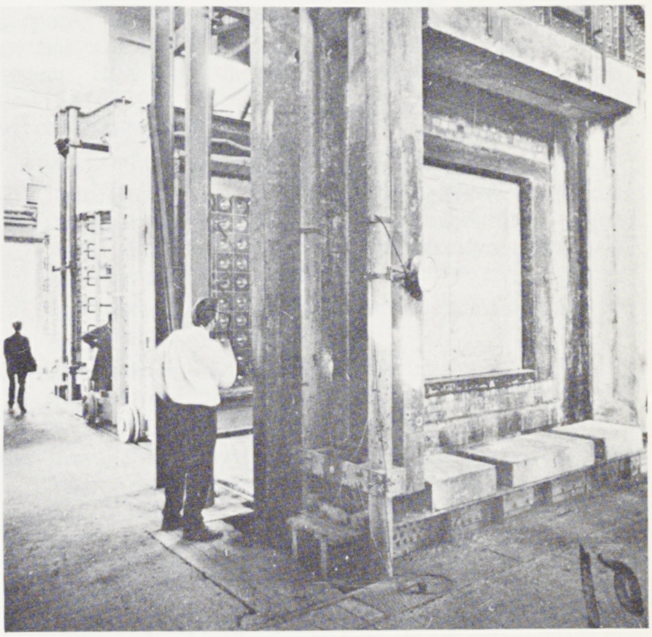


Plate 3

Structural fire protection test at laboratory

Doors in fire divisions should have a similar fire rating to the division in which they are fitted. Ventilation openings or louvres may be fitted in the lower half of B-15 Class doors, however they should not be fitted in doors of divisions forming stairway enclosures or in A-Class divisions.

Openings in all bulkheads and decks in the accommodation spaces are required to have permanently attached means of closing which will maintain the fire integrity of the division.

Where fire divisions are penetrated by electric cables, pipes, trunks, structural members etc., the arrangements should be such that the fire-resistance is not impaired. For small pipes and electric cables this may be achieved by the use of proprietory glands that have been subjected to a standard fire test or by specially made up sleeves packed with insulating material of known properties. For larger diameter pipes, proprietory seals such as the Bestobell type may be used. Alternatively, a larger diameter pipe sleeve with the annular space filled with insulating material of known properties or a fully welded pipe spool suitably insulated may be used. Figure 3 shows typical details of fire division penetrations. In each case the objective is to create a barrier to the passage of smoke and flame and provide sufficient insulation along the penetration to eliminate the 'heat bridge' effect. A minimum distance of 380 mm is required for this unless a shorter distance has been established by a standard fire test.

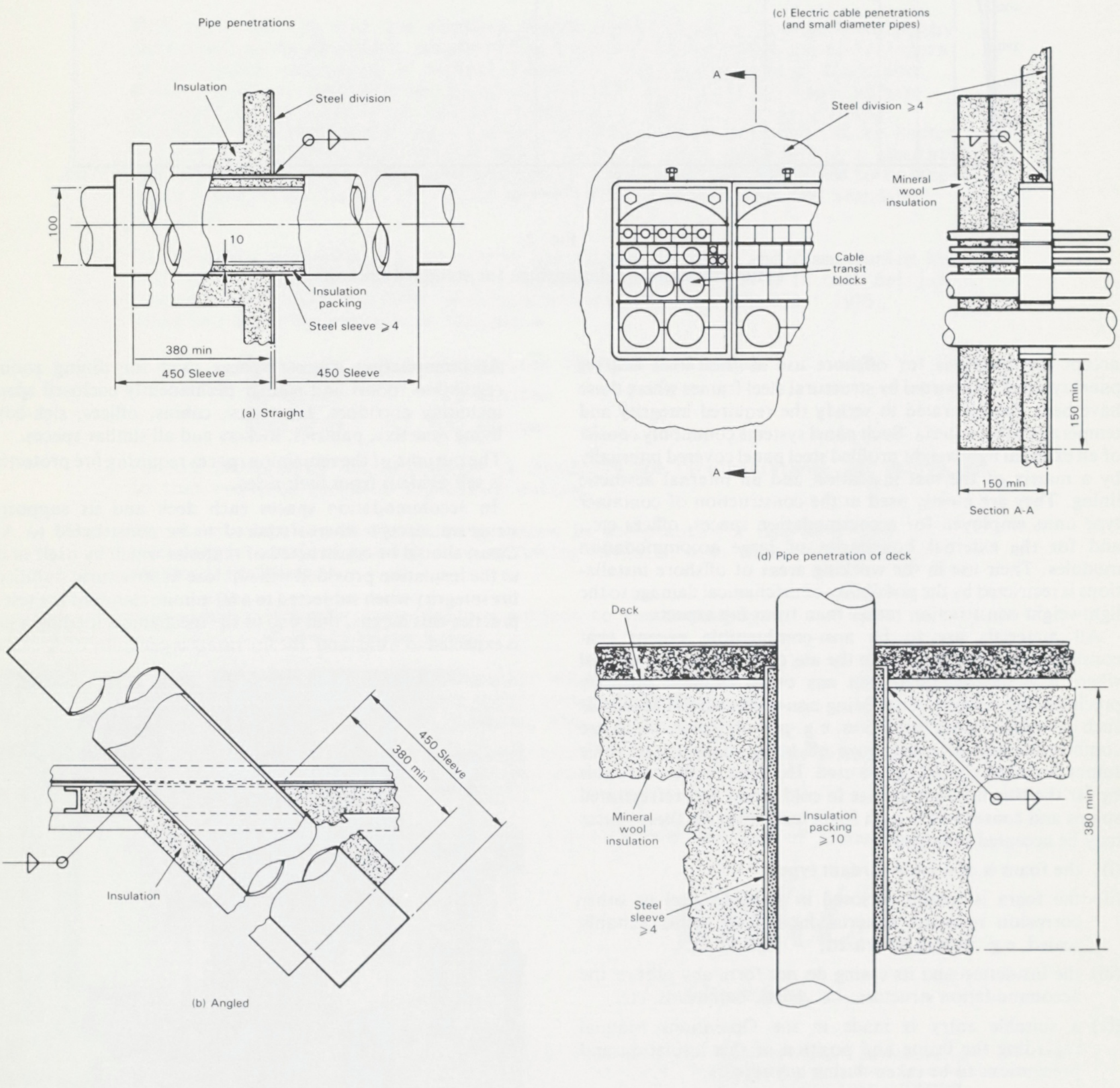


FIG. 3

Typical details of fire division penetrations

Air spaces enclosed behind ceilings, panellings or linings should be divided by close-fitting draught stops spaced not more than 14 metres apart. Draught stops should be fitted transversely if the length of the space exceeds 14 metres and lengthwise if the breadth exceeds that dimension. This is sometimes achieved by extending the cabin divisions from deck to deck at regular intervals; alternatively light gauge sheet steel that is easily formed and cut with hand snips may be used. There are no scantling requirements for draught stops, only that the materials should be non-combustible. Where pipes and electric cables penetrate the draught stops any gaps caused should be packed or sealed with a non-combustible material.

Internal stairways, ladders and crew lift trunks within the accommodation areas should be constructed of steel or equivalent materials. Stairways serving more than two decks should be enclosed within a trunk constructed of A-60 Class divisions and have self-closing doors. Stairways connecting only two decks need only be enclosed at one level by divisions having the same fire integrity and structural stability as the deck and having self-closing doors. Stairway enclosures should be in direct communication with the escape corridors.

All boundaries of control stations should be A-60 Class divisions. Windows in A-60 Class divisions are not recommended, however where these are necessary they should be glazed with diamond mesh wired glass and fitted with permanently attached steel shutters; alternatively the window assembly should be approved as complying within the A-60 requirement in its own right. The contiguous boundaries of adjacent spaces defined as control stations are required to be constructed to A-60 Class. However, contiguous boundaries not of A-60 Class could be accepted where the essential purpose of adjacent control stations is similar.

Boundaries separating any machinery space, or storeroom containing paint, oil, gases or other inflammable materials, from any galley or accommodation space, should be A-60 Class divisions. Boundaries separating these spaces from each other should be of non-combustible material which will not lose its fire integrity after being subjected to a standard fire test for one hour. The surfaces of insulating materials fitted to the inside of bulkheads and decks forming the casings and crowns of compartments containing or affected by oil or oil vapour should be impervious to oil and oil vapour.

Boundaries separating accommodation spaces from any galley or any pantry containing cooking appliances should be constructed of non-combustible material which by itself or due to insulation provided will not lose its fire integrity when subjected to a 60-minute standard fire test. Doors and the shutters to serving hatches should be capable of being readily closed from a position outside the galley or pantry and be so constructed that the integrity of the bulkhead is maintained.

Where galley supply or exhaust ventilator trunking passes through accommodation or any other enclosed spaces the trunking within those spaces should be of steel covered with a fire-resisting insulation material of a type and thickness acceptable for an A-60 Class division.

Bulkheads separating the accommodation area from well-head or process areas should be A-60 Class divisions. Alternatively other equivalent fire protection may be provided between the accommodation and these areas.

Primary deck coverings should be of a type which will not readily ignite and should be suitable for the intended service. Paints, veneers and other surface finishes used on surfaces in concealed or inaccessible spaces and on exposed surfaces (except furniture, furnishings and floor coverings) should have low flame spread characteristics. Pipes intended to carry oil or other combustible fluids or gases (other than those concerned with the primary process of the installation) should be of a material and construction acceptable to the certifying authority. Overboard scuppers, sanitary discharges or other outlets which may give rise to the danger of flooding should be of a material unlikely to fail in the event of fire.

It is frequently necessary for diving operations to be carried out from offshore installations. For manned submersible operations a diving control cabin will be required and a basic philosophy on materials for such control cabins has been established. Whilst not mandatory, it is recommended that the cabin materials should give maximum fire protection to the control personnel. Therefore, where possible, the material to be used on all external boundaries should be A-60 Class. This would allow the cabin to be transportable to any position on the installation even in a hazardous area, if necessary, without affecting a Certificate of Fitness, subject to adequate air pressurisation and electrical equipment of suitable standard being installed.

2.4 **Plans required for appraisal**

2.4.1 Structural Fire Protection

The plans and necessary supporting documentation required for appraisal are listed hereafter and should clearly show the required information:

(i) A general arrangement drawing of the platform showing the location and rating of each fire wall. The purpose of the spaces enclosed by the fire walls should be stated.

(ii) Construction details of each type of fire wall, including materials of construction, density and thickness of insulation, method of attachment to main structure and interpanel attachment.

(iii) Protection of fire walls in way of penetrations (ventilation ducts, doors, pipes and cables), and heat bridges.

(iv) Certificates of Approval or suitable fire test data in respect to the fire resistance ratings of designated fire divisions, both internal and external, doors, shutters, ceiling constructions, etc. Approval authorities may be Lloyd's Register or in some cases the national authorities in the country of manufacture.

(v) Layout of escape routes.

2.4.2 Firefighting Systems

The approval of those systems required for compliance with Statutory Instrument 1978, No. 611, is not the responsibility of Lloyd's Register this work having been delegated to the DOT by the D.En. However, the Society is responsible for ensuring that the construction of the systems is suitable for the intended purpose. The systems comprise fire water-main and deluge systems, automatic sprinkler systems, fire and gas detection systems, fixed fire extinguishing systems required by Regulation 13 of SI 1978, No. 611, and fire-fighting systems protecting helicopter landing areas.

To this end the following information is required.

(i) Specifications of the systems or extracts therefrom, sufficient to define the construction standards of piping, valves, fittings and jointing and to identify materials and fittings which require to be fire tested.

(ii) The power sources for the control systems of fixed fire extinguishing systems.

(iii) The location of fire pumps, driving units and energy sources, to establish that a fire in any one compartment will not impair the required water supply.

(iv) If available, a key diagram showing the layout of the fire-fighting systems in relation to the general arrangement of the installation.

2.5 **Fire Test for Fire Main Fittings**

Valves, cocks and other fittings having materials which could be readily rendered ineffective by heat are not acceptable in fire main systems unless they can withstand a suitable fire test as follows:

(i) TEST PROCEDURE

The valve or other item to be tested should be placed in a suitable furnace or oven where a temperature of 540°C should be maintained for 20 minutes, during which time an internal water pressure, without flow, of 8.3 bars should be maintained on the item. At the end of the test the leakage should not exceed 22.7 litres per minute.

(ii) TEST CONDITIONS

Hydrants, valves and cocks should be tested in the closed position. Hydrants should be tested with the outlet hose connection open, i.e. with no cap on. Isolating valves and similar valves and cocks should be tested with pressure on one side of the valve or cock and may have an open ended pipe connected to the other side of the valve or cock leading outside the furnace.

(iii) EXEMPTIONS

Valves having metal to metal valve lids and seats, and cocks having metal bodies and plugs, are normally acceptable without a fire test.

Compressed asbestos fibre jointing not thicker than 1.6 mm, and other jointings not thicker than 0.8 mm, may be accepted without test, except neoprene and other materials with similar melting points.

2.6 Fire Test for Flexible Hoses

From time to time the Society has been requested to witness fire tests of flexible hoses intended for use on exploration and production offshore installations and issue appropriate certification. Such requests have included flexible hoses for use as:

(a) Hydraulic control lines for blow-out preventers and valves.

(b) Jumpers linking wellhead 'christmas trees' to choke manifolds on production rigs.

(c) Mud, kill and choke lines on drilling rigs.

(d) Jumpers linking platform and drill deck fire water mains.

It has been considered inappropriate to give general approval for the intended use of the hoses. Instead each submission is considered on its merit. However it is expected that all hoses submitted for approval should satisfy suitable fire test requirements. Whilst at the time of writing the development of test requirements has not been concluded, the following may be anticipated:

1. A representative test piece of the prototype hose is to be heated from ambient temperature until a temperature of 700°C is reached 10 minutes after the start. This temperature is to be maintained for a further 15 minutes until the end of the test except in the case of hydraulic control lines when the temperature need be maintained only for 5 minutes after reaching 700°C.
2. The fire test is to be carried out under the following conditions:
   - (i) The test piece is to be heated in a furnace to ensure accurate temperature control.
   - (ii) The test piece is to include at least one end coupling.
   - (iii) The length of the test piece which is to be heated is to be not less than 'L' metres, where

$$L = \frac{\text{Nominal hose diameter (mm)}}{300} + \text{1.5 (excluding end coupling)}$$

   - (iv) Temperatures are to be measured at the middle and ends of the test piece by pairs of thermocouples located 25 mm from the surface of the test piece.
   - (v) The test piece is to be internally pressurised with water to working pressure before the start of the test. This pressure is to be maintained during the test without further addition of water.
   - (vi) A successful result will be deemed applicable to a range of sizes of plus and minus 30% of the nominal diameter of the test hose for use at the working pressure specified for the test.
   - (vii) Alternative proposals of conditions under which the test specified in paragraph 1 may be carried out will be specially considered.
3. Acceptance of hoses in categories (b), (c) and (d) will be conditional on arrangements being provided to isolate the hoses in the case of emergency or replacement.
4. Compliance with other non-related requirements may also be necessary to establish the suitability of hoses in all respects for their intended purpose.
5. Notwithstanding the above, the hoses are also to be acceptable to the National Authority concerned.

Fire tests should preferably be carried out at recognised testing establishments. The design and construction of the test rig is to be suitable for the intended pressure. Relief arrangements are to be provided to prevent over-pressurisation including that caused by heating, and in the event of failure of the test piece, to ensure that the energy released can be safely dissipated.

It is proposed that flexible hoses on offshore installations be visually examined and pressure tested or replaced annually.

3. FIXED INSTALLATIONS OUTSIDE U.K. WATERS

To date the Society has dealt with the plan appraisal of fire safety aspects of fixed installations located in the territorial waters of several countries other than the U.K. including New Zealand, Australia, Brazil, India, Abu Dhabi, Egypt, Netherlands and Ireland. Statutory requirements for such installations have not yet been established in some of these countries but, in some cases, the Administrations concerned have requested compliance with the requirements of the U.K. Department of Energy as if the installation were to be located in U.K. waters.

In other cases, where the Administration has not made any such recommendations, the prudent Owner has sought certification of the proposed fire safety arrangements by a Classification Society such as Lloyd's Register. The Society's requirements are based generally on those of the U.K. D.En. i.e. SI 289, 1974 for structural fire protection and escape routes and SI 611, 1978, the Offshore Installations (Firefighting Equipment) Regulations, for fire detection and extinction aspects.

Thus the contents of the previous Sections 2.2 to 2.6 are also applicable to fixed installations outside U.K. waters. However, whereas the fire safety aspects of the U.K. Certification Scheme are restricted to structural fire protection, materials of construction and escape routes, the Society in these other cases also carries out plan appraisal of the following:

(a) Automatic fire detection systems.

(b) Flammable gas detection and measuring systems.

(c) Fire alarm systems.

(d) Remote control safety equipment.

(e) Fire mains, water deluge systems, water monitors and hydrants.

(f) Automatic sprinkler systems.

(g) Fixed fire extinguishing systems.

(h) Helicopter landing area equipment.

(i) Portable firefighting equipment.

3.1 **Automatic Fire Detection Systems**

An automatic fire detection system is required throughout the working spaces of an offshore installation, the definition of such spaces being—'any workshop, engine room or generator room and any space containing equipment in which petroleum or any other flammable substance is stored, conveyed, processed or consumed'.

The basic objective is to provide an automatic system to monitor all working spaces on the installation for incipient fire conditions and alert the personnel normally present to the existence and location of the condition. In the case of installations which are not normally manned the alert should be transmitted to the personnel on another installation in the field or, in some cases, to a control room ashore. The system should be capable of indicating the presence of a fire in any of these spaces, both audibly and visually, at a 'control point' (see also the definition in Section 2.2) or at another location which is continuously manned should the control point be unmanned at any time.

The system should be self-monitoring for faults which could effect the operational efficiency of the system. Detection of such a fault should be indicated by an alarm clearly distinguishable from that arising from detection of a fire. Activation of a detection device in any particular space or zone should not prevent signals from other detection devices in other spaces or zones from registering at the control point. Additionally the alarm provisions required for the systems indicated by (b), (c) and (f) above would normally be grouped with the fire detection alarm at the control point. The signals from these systems may be used to initiate other items of firefighting equipment provided that this does not detract from the operational efficiency of the detection system.

At least two detectors of a type suitable for the anticipated hazards should be provided in any working space but these need not be of the same type. Often it is desirable to fit a combination of types to provide the most efficient monitoring. The types of detectors shown in table 1 would be suitable for use on an offshore installation.

Additionally, plan appraisal to verify compliance with the following will be required by the Society's Electrical Engineering Department:

(a) power sources (including changeover arrangements); cabling and switchgear; associated control circuitry;

(b) suitability of equipment for use in hazardous atmospheres.

TABLE 1

Detector type	Limitations or precautions
Thermal	(i) Should be of the self-resetting type. (ii) Should not be fitted in spaces with a roof, ceiling or overhead covering higher than 8 m. (iii) Should monitor not more than $37m^2$ of horizontal area. (iv) Response requirements should meet BS 5445 Part 5: 1977 (CEN Standard EN 54; Part 5)
Smoke (optical)	(i) Full account should be taken when siting such detectors of the possiblity of stratification of smoke or products of combustion within the protected space particularly in the early stages of a fire. (ii) Full account should be taken of the effect of ventilation arrangements on flow patterns within the spaces particularly where such ventilation arrangements can be varied.
Smoke (Ionization type)	As for Smoke (optical)
Flame	Should generally be of the ultra-violet type in open areas.
Frangible bulb	Operating temperature should be not more than 30°C above the normal ambient temperature but need not be less than 57°C.
Remote sampling of atmosphere in space	Can be considered if meeting all other requirements of this Section and subject to continuous monitoring of the space concerned.

The scope of initial and subsequent examinations by the Outport Surveyors should generally cover the following:

Initial Examination

(a) to establish that the system has been installed in accordance with approved plans;

(b) to conduct sufficient functional simulation tests to assess the operational efficiency of the various detectors/detector circuits; in this respect responsibility rests with the installation owner to devise acceptable test methods, provide any necessary test equipment and allocate any test personnel required;

(c) to establish that all associated audible and visual alarms function efficiently;

(d) to establish that sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

As for (b), (c) and (d) above and additionally establish that no unauthorised modifications have been made.

3.2 **Flammable Gas Detection and Measuring Equipment**

An automatic flammable gas detection system capable of continuously monitoring every part of the installation in which flammable gas may accidently accumulate is required for all installations. The system provided on manned installations should be capable of indicating, both audibly and visually, the presence of an accumulation of flammable gas and its location at the control point referred to in the previous section and at another place which is continuously manned should the control point not be so. On unmanned installations the indication should be given at a continuously manned place on another installation in the field or ashore. At least two portable flammable gas measuring devices are to be provided on all installations although, for the unmanned installation, it is preferable that the portable measuring devices are not stowed there but taken by the visiting personnel.

The fixed system should be so arranged as to continuously monitor all parts of the installation where flammable gases may accidentaly accumulate and, upon detection of an accumulation which exceeds preset limits based on a percentage of the lower explosive limit (LEL), give a suitable audible alarm and simultaneous visual alarm at the control point. The audible alarm should be distinct from all other installation alarms and from any expected background noise. Similar to the fire detection system, the gas detection system should be self-monitoring for faults and register a distinguishable alarm on detection of a fault.

The flammable gas detection alarm setting for the system should be at the lowest possible level consistent with an absence of alarms generated by normal operations on the installation. In practice a low level alarm at 20% LEL and high level alarm at 60% LEL are often selected although the system should also incorporate features which will permit the operational personnel to make any necessary adjustments to the sensitivity of individual alarm settings. Where the system coverage is relatively large then the system should incorporate features which will permit personnel at the control point to ascertain at any time the percentage concentration based on the lower explosive limit in any monitored space. Means should also be provided, whereby operational personnel may readily check on the accuracy of any such percentage reading obtained and carry out any calibration adjustments considered necessary.

Systems operating on a sequential sampling principle are not acceptable because they do not provide continuous monitoring. This, however, does not preclude sampling systems which, by virtue of sophisticated control devices or whatever, are capable of providing essentially continuous and effective monitoring. Irrespective of operating principles the system should respond rapidly and efficiently to an accumulation of flammable gas in any of those parts of the installation monitored by the system.

The sensors of sampling points monitoring particular parts of the installation should be sufficient in number and suitably sited, so as to provide effective monitoring of the part in question during all normal anticipated working conditions. Particular attention should be given to ensuring that the siting of sensors or sampling points is in accordance with the anticipated pattern of air movements and the particular flammable gases or vapours liable to be present. Additional requirements concerning the location of sensors or sampling points are given in SI 289, 1974, that in the arrangement of ventilation, heating and cooling systems, consideration should be given to the detection of escaped gas from hazardous areas at the fresh air inlets to safe areas. Any circuit or piping associated with the systems should be suitably protected and routed to minimise the possibility of damage from fire or mechanical causes. Provision should be made to enable the fixed system to be tested without disruption to the normal routine operation of the installation.

Additionally, plan appraisal to verify compliance with the following will be required by the Society's Electrical Engineering Department:

(a) power sources (including changeover arrangements); cabling and switchgear; associated control circuitry;

(b) suitability of equipment for use in hazardous atmospheres.

The scope of initial and subsequent examinations by the Outport Surveyors should generally cover the following:

Initial Examination

(a) to establish that the system has been installed in accordance with approved plans;

(b) to conduct sufficient functional simulation tests to assess the operational efficiency of the various detectors/detector circuits; in this respect responsibility rests with the installation owner to devise acceptable test methods, provide any necessary test equipment and allocate any test personnel required.

(c) to establish that all associated audible and visual alarms function efficiently;

(d) to establish that sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

As for (b), (c) and (d) above and additionally establish that no unauthorised modifications have been made.

3.3 Fire Alarm Systems

The system should comprise a series of manually activated call points generally sited at, or near, doorways and exits on recognised access or escape routes which will indicate the presence of a fire at the control point and at another continuously manned place on the installation if the control point may be unmanned at any time. The signal given at the control point should be both audible and visual to the control personnel.

The visual alarms should be displayed in such a manner as to readily identify the location or zone in which the manual call point has been activated. The alarm given by any manual call point should not prevent signals from any other call point, located in another zone, from registering at the same time.

The system should be self-monitoring for faults and give an alarm clearly distinguishable from that arising from actuation of the call points. The audible indication of a fault could be the same for all detection systems with the visual indication showing the zone concerned. Suitable provision should be made to enable both the alarm and fault modes of the system to be tested without disrupting the normal routine operations of the installation.

Additionally, plan appraisal to verify compliance with the following will be required by the Society's Electrical Engineering Department:

(a) power sources (including changeover arrangements); electrical cabling and switchgear; associated control circuitry;

(b) suitability of equipment for use in hazardous atmospheres.

The scope of initial and subsequent examinations by the Outport Surveyors should generally cover the following:

Initial Examination

To establish that:

(a) the system has been installed in accordance with approved plans;

(b) the system as a whole functions in a satisfactory manner by practical tests;

(c) sufficient and suitable operational and maintenance data have been provided.

Subsequent Examinations

As for (b) and (c) above and additionally establish that no unauthorised modifications have been made.

3.4 Remote Control Safety Equipment

The equipment requirements of this section relate only to safety equipment other than that provided specifically for drilling operations or the safety of the production process.

The basic objectives of the remote control safety equipment are to provide suitable equipment, capable of remote manual operation, which, when actuated in the event of fire emergency, will aid the control of the fire by the following means as appropriate:

(a) shutdown of any related powered ventilation system;

(b) closing of any related ventilator or similar opening;

(c) shutdown of any related equipment used to pump fuel;

(d) securing the outlets from any related fuel pressure vessels or storage tanks.

The equipment provided for these purposes should be capable of operation from a position which is outside the relevant room where the fire emergency originates. The remote manually operated controls for all such equipment should be centralised, as far as is reasonable and practicable, in clearly

marked positions which would be unaffected by a fire in any of the spaces served by the devices. On normally manned installations this is usually the control point referred to in previous sections.

Means should be provided at the control point to indicate the status of the control system. The safety devices should include features which will permit 'fail safe' operation and where the operation is by hydraulic, pneumatic or other pressurising means, the following features should be incorporated:

(i) A pressure gauge or equivalent means at the remote control operating station to indicate the status of the system.

(ii) The system should have sufficient stored capacity to operate all safety devices at least once without recharging.

(iii) Means should be provided for recharging the system.

Where operation is by electrical means the following should apply:

(i) Monitoring devices should be provided at the control operating station to indicate the operational status of the system.

(ii) The system should have duplicate sources of power one of which being the emergency source.

Circuits and piping associated with the system should be suitably protected and routed to minimise the possibility of damage arising from fire or other physical causes. In particular, the amount of such circuits and/or piping within spaces or rooms, in which safety devices are located, should be kept to a minimum. Where a number of safety devices are operated by a single control loop or circuit then failure of any single device to operate should not prevent the operation of the remainder.

In respect of safety devices associated with ventilation systems and ventilators, consideration should be given to providing a type of device which will, after operation during a fire emergency, also permit the ventilation system or ventilators to be operated in such a manner as to assist efforts being made to control the emergency, e.g. dispersal of smoke. Remote operation by means of a pull wire arrangement is not recommended as the wire may stretch unduly in a fire. However, arrangements incorporating only a short length of wire could be considered. The wire should be of steel. Where windows or glass panels have a lower fire rating than the boundaries in which they are fitted, steel covers or shutters should be provided and reference is made to Section 2.3 concerning the structural fire protection requirements for A-60 Class divisions.

Doors to rooms containing a recognised fire hazard should be self closing and hold-back facilities should not be fitted unless these are of a type that can be released remotely and are fail-safe in operation. Where any safety device is arranged for automatic operation this should be in addition to the manually operated remote controls. Suitable provisions should be made to enable the equipment to be readily tested without disrupting the normal routine of the installation.

Additionally, plan appraisal to verify compliance with the following aspects will be required by the Society's Electrical and Mechanical Engineering Departments:

(a) any associated electrical, pneumatic or hydraulic power sources;

(b) suitability of electrical equipment for use in hazardous areas.

The scope of initial and subsequent examinations by the Outport Surveyors should generally cover the following:

Initial Examination

To establish that:

(a) all equipment has been installed in accordance with approved plans;

(b) all equipment functions as intended (both manual and automatic);

(c) all associated indicating devices function as intended;

(d) sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

As for (b), (c) and (d) above and additionally establish that no unauthorised modifications have been made.

3.5 Fire Pumps, Firemains, Water Deluge Systems, Water Monitors and Hydrants

The backbone of any firefighting system is the efficient operation of the fire water main by which an adequate supply of water can be delivered to any part of the installation for extinguishing purposes. At least two fire water pump units are required. However, whatever the number of pump units, they must be arranged so that the fire pumps remaining in operation after an outbreak of fire in any compartment can provide 100% of the maximum required water demand and maintain this for a period of at least 12 hours.

Separate fire mains for the installations hydrants and deluge systems may be provided, each fire main being connected to its own pumps. Alternatively all the fire water services may be taken off the one fire main. Table 2 lists the various options available. Where the helideck foam system (Section 3.8) and the accommodation sprinkler system (Section 3.6) are taken off the fire mains shown in the table, then with either system in operation it should still be possible to maintain a pressure of at least 3.5 kg/cm^2 at any two hydrants when supplying hoses

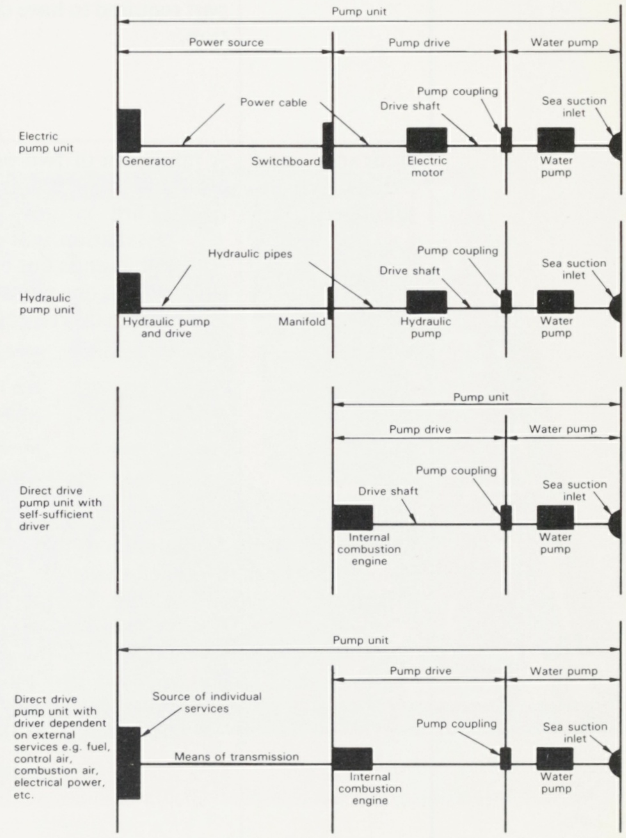


Fig. 4

Examples of typical pump units

fitted with plain 19 mm bore nozzles. Simultaneous operation of the helideck and accommodation sprinkler systems with any part of the deluge system is not required.

The use of the word 'pump' is taken to mean both the pump and its source of power and to indicate this more clearly the term 'pump units' has been used, some typical pump unit arrangements being shown in Fig. 4.

Pump units should be arranged to draw water directly from the sea. Where the design or structural configuration of an installation makes this onerous, an alternative could be a two stage arrangement, where the required pump units draw from an intermediate tank or watermain supplied by pumps drawing directly from the sea. In such instances the supply pumps will be regarded as the required pump units and should therefore conform with the appropriate parts of this Section. Any water pump connected to a fire watermain should be provided with a suitable manually operated isolation valve between the pump and the connection to the main and, where appropriate, on the suction side of the pump. Where appropriate these valves should be arranged for remote operation. Any water pump of the centrifugal type connected to a water main should be provided with a non-return valve on the discharge side of the pump.

Those pump units located within or adjacent to a part of the installation which requires deluge protection should be effectively isolated from that part by steel divisions. The

TABLE 2

Fire main for:	Minimum Number and Arrangement of Pump Units	Pump Discharge Capacities
Hydrants only	A minimum of two pump units so arranged that a fire in any part of the installation will not put both pump units out of action.	The minimum discharge from each pump unit to be sufficient to maintain simultaneously a pressure of at least 3.5 kg/cm² at any two hydrants when supplying hoses fitted with plain 19 mm bore nozzles;
Deluge Systems only	A minimum of two pump units one of which should be outwith any part required to have deluge protection.	The minimum discharge from each pump unit to be sufficient to maintain at a suitable pressure a supply of water for the efficient operation of the deluge system protecting the largest single area requiring deluge protection;
Deluge Systems only	A minimum of three pump units two of which should be outwith any part required to have deluge protection.	The minimum discharge from any two pump units to be sufficient to maintain at a suitable pressure a supply of water for the efficient operation of the deluge system protecting the largest single area requiring deluge protection.
Hydrants and Deluge Systems combined.	A minimum of two pump units so arranged that: (i) a fire in any part of the installation will not put both pump units out of action; and (ii) at least one pump outwith any part required to have deluge protection.	The minimum discharge from each pump unit to be sufficient to maintain: (i) at a suitable pressure a supply of water for the efficient operation of the deluge system protecting the largest single area requiring deluge protection and; (ii) a pressure of at least 3.5 kg/cm² at any two hydrants when supplying hoses fitted with plain 19 mm bore nozzles.
Hydrants and Deluge Systems combined.	A minimum of three pump units so arranged that: (i) a fire in any part of the installation will not put all pump units out of action; and (ii) at least two pump units are outwith any part required to have deluge protection.	The minimum discharge from any two pump units to be sufficient to maintain; (i) at a suitable pressure a supply of water for the efficient operation of the deluge system protecting the largest single area requiring deluge protection; and (ii) a pressure of at least 3.5 kg/cm² at any two hydrants when supplying hoses fitted with plain 19 mm bore nozzles.

protection afforded by such divisions should, together with any associated thermal insulation and/or water protection be sufficient to ensure successful operation of the pump unit for at least 12 hours in the event of a major fire emergency in the adjacent part. Compartments housing any part of a pump unit should be properly illuminated, efficiently ventilated and readily accessible under both normal and emergency conditions.

It would normally be expected that water mains would be filled with water and that suitable provision would be made for the automatic start-up of pump units if the pressure in the fire main dropped below preset limits. Where automatic start-up is not envisaged then remote start-up facilities for pump units and, where appropriate, remote operation of associated suction and discharge controls should be fitted at strategic locations. In all cases it should be possible to start pump drives locally. Sufficient instrumentation both local and, where appropriate remote, should be provided to enable attendant personnel to ascertain the operational status of any pump unit. Particular attention should be paid to the protection against damage of any associated power cables, hydraulic pipelines, fuel pipelines, and control circuits.

Pump units, once actuated, manually or otherwise, should be capable of operating automatically for at least 12 hours (i.e. unattended operation). To meet the intent of the requirement it will be necessary, in those cases where pump units are dependent either wholly or to a degree for their operation on services supplied from the installation, e.g. electrical power, control air, etc. to ensure that in event of a fire emergency the operation of any emergency shutdown procedures/systems will not affect the essential services to the pump units or, failing this, that some effective alternative service(s) is (are) provided. In this respect particular attention is drawn to the following services:

(i) electrical power;
(ii) control air;
(iii) fuel;
(iv) combustion and cooling air.

The starting arrangements for internal combustion engines forming part of a pump unit should have sufficient capacity to permit at least 6 starts in a period of 30 minutes including at least 3 starts in the first 10 minutes.

The routing of the fire main and location of hydrants should be such that a minimum of two jets of water from hoses attached to separate hydrants can be brought to bear on a fire in any part of the installation, one of which being from a single length of hose. The nozzles should be capable of producing a water jet, water spray and water fog. Sufficient isolating valves are required such that in the event of damage to any part of the fire main it will be possible to keep the intact part of the fire main in operation. Also, when the combined main is used for the hydrants and deluge systems, the routing of the fire main and location of isolating valves should be so arranged that, as far as practically possible, damage to any single part will not affect the supply of water to an adjacent fire zone assuming that entry to the effected zone for the manual operation of valves would not be possible. Where appropriate, automatic pressure relief devices are to be fitted. These should be arranged such that closure of any isolating valve or valves will not leave any part of the main unprotected. When a combined fire main for hydrants and deluge systems is provided care should be taken to ensure that the pressure at hand-held firefighting equipment will permit the safe operation of the equipment by the installation's personnel.

Fire hoses of 64 millimetres bore and of 18 metres length made of unlined canvas are considered as standard in the industry but lined fire hoses of smaller bore will be accepted provided tests have shown that the pressure drop across an 18 metres length approximates to that across an 18 metres length

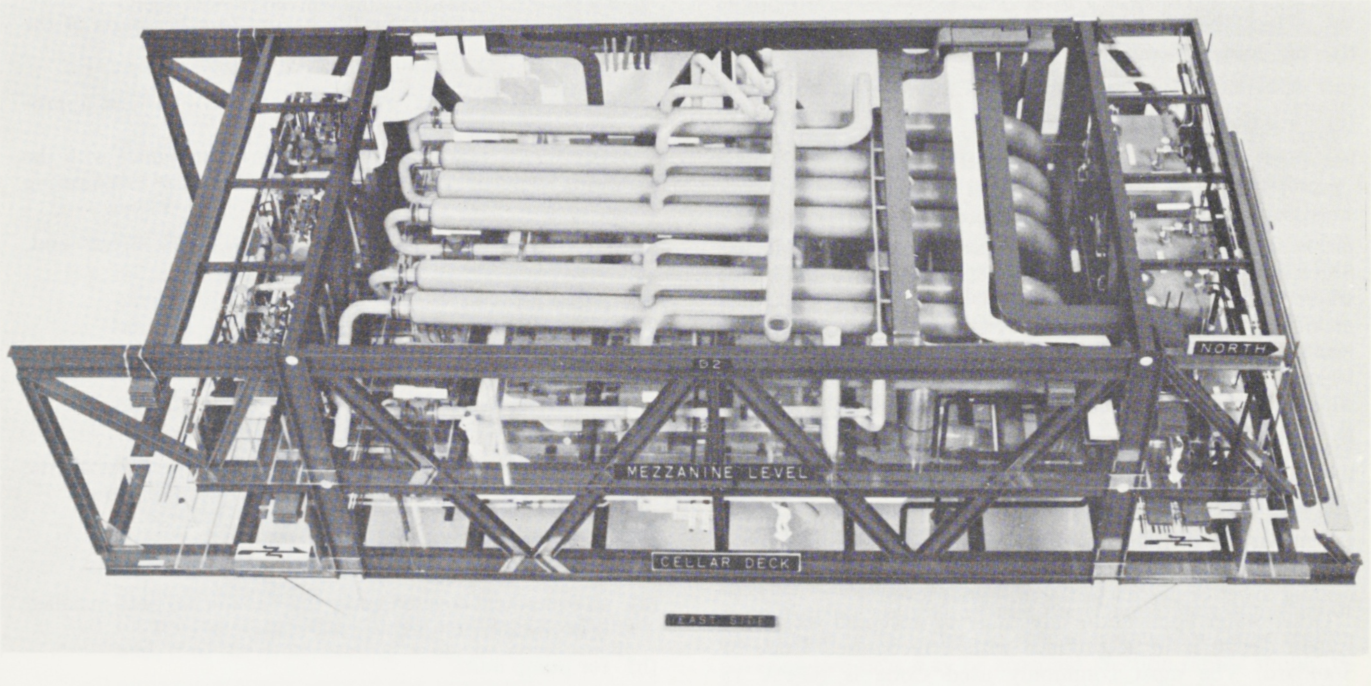


PLATE 4

Platform model showing typical pipework requiring deluge protection

of unlined 64 millimetres canvas at 3.5 bars. Certain lined hoses of 45 millimetres bore have been shown to have a throughput comparable to that of a 64 millimetres bore unlined canvas hose at corresponding pressures. As the smaller bore hose is more easily handled and will produce an identical jet, this hose is preferred. Nozzles for use with standard hoses should preferably incorporate a shut-off device and have a throw of at least 12 metres associated with a minimum discharge of 26 m^3/hour at a pressure of not less than 3.5 bar. When on spray setting they should produce a reasonably fine spray or fog which can be arranged to form a water curtain behind which it would be possible to approach a fire. An acceptable cone diameter of the fog would be about 5 metres at a distance of about 2 metres from the nozzle.

Permanently connected hose reel units using smaller diameter non-collapsible hoses may be provided within accommodation spaces in order to allow any one person to attack a small fire without delay. However these small diameter hoses would be additional to the required hydrants and hoses.

Certain parts of the installation will contain equipment for petroleum production/processing and drilling/workover operations which, if exposed to heat from a fire, could give rise to the risk of a BLEVE (boiling liquid expanding vapour explosion) if ruptured. They should be protected by a cooling water spray (deluge system).

The following areas are typical of those parts of an installation which will require protection by a deluge system or water monitors or a combination of both:

(a) wellheads;

(b) crude/gas separation equipment;

(c) gas compressors;

(d) liquefaction plant;

(e) gas pressure vessels;

(f) crude oil pumps;

(g) crude oil and gas manifolds/piping (not fuel gas) including piping routed over bridges between platforms;

(h) crude oil storage vessels or tanks;

(i) gas liquids/concentrate storage vessels;

(j) Glycol regeneration plant;

(k) flare knockout drums;

(l) pig launchers/receivers;

(m) de-aereation/filtration equipment (if using gas);

(n) drill floor/workover areas;

(o) areas containing equipment (including piping) through which petroleum will flow during well test operations.

The quantity of water supplied to any part requiring protection should be at least sufficient to provide 'exposure protection' to the relevant equipment within that part and, where appropriate, local principal load bearing structural members where the latter are not suitably protected by fire insulation. Normally the quantity of water supplied should not be less than 12.2 litres/metre^2/minute over the 'reference area' which is that bounded completely by:

(i) vertical A-Class divisions, or

(ii) the seaward extremities of the installation, or

(iii) a combination of (i) and (ii),

except for the drill floor/workover area where the reference area is that included within the boundaries of the base of the drilling tower or derrick at the drill floor level.

Other water application rates may be accepted where the system design is in accordance with a recognised Code or Standard. The most commonly used Code is NFPA 15 (National Fire Protection Association, U.S.A.) which details the water requirements for vessels, pipe racks (of any number of levels), structures and other miscellaneous equipment. The Code also gives a standard format for the presentation of the hydraulic calculations required to verify that the intended water application rate can be achieved by the pumps and piping system.

Depending on the prevailing circumstances each part requiring water protection should be provided with a primary means of application which may be:

(i) a fixed system of piping fitted with spray nozzles, or

(ii) water monitors, or

(iii) a combination of both.

Water monitors, however, can be allowed only for the protection of equipment in essentially open areas and should be capable of delivering the required quantity of water irrespective of the prevailing weather conditions.

A shut-off valve, capable of manual operation, should be provided at the point where each branch line serving a pipe-nozzle system is taken off the supply main. This point should be outside the reference area being protected and not likely to be affected by a fire in that area.

Automatic operation of water protection systems is not specifically required. It is recommended, however, that wherever possible and practicable, particularly on large fixed installations, such automatic operation be provided. In general any device employed to permit automatic operation, i.e. section control valves etc., should have a local manual override function, both to provide an alternative means of operation in the event of failure of the automatic mode and to permit selective control over the deluge sections as a whole during an emergency.

Failure of operation of any section control valve should not prevent the operation of the remainder of the section control valves.

Consideration should be given to preserving the integrity of any A-Class division which bounds parts requiring water protection by ensuring that such divisions are afforded effective cooling when the relevant water protection system is operated.

Where stored flammables other than petroleum, e.g. methanol, aviation fuel, acetylene in cylinders, chemicals etc., could either:

(i) be affected by a fire in an adjacent part; or

(ii) in themselves present a fire hazard to other parts of the installation;

then it is expected that water protection will, where appropriate, be provided to the storage space.

Additionally, plan appraisal to verify compliance with the following will be required by the Society's Engineering Departments:

(a) construction and surveys of pumps, their drives and, where applicable, their power sources;

(b) pump caissons;

(c) construction of fittings, piping and jointing;

(d) suitability of equipment for use in hazardous atmospheres.

The scope of initial and subsequent examinations by the Outport Surveyors should generally cover the following:

INITIAL EXAMINATION

To establish that:

(a) all equipment covered under this Section has been installed in accordance with approved plans.

(b) for pump units;

  (i) each unit is capable of passing at sufficient pressure the quantity of water specified in the appropriate part of table 2;

(ii) where appropriate all associated valves, instrumentation, safety devices, control devices and starting arrangements function as intended;

(iii) with the status of the installation's emergency shut down system assumed to be at a level according to a major fire emergency, sufficient services, e.g. electrical power supply, control air, ventilation, cooling water, fuel supply, remain available to enable all required pump units to operate efficiently at full load. Under these conditions each pump unit should be run for at least 4 hours;

(iv) that sufficient instructional and operational data have been provided.

(c) for fixed pipe-nozzle deluge systems;

(i) all piping and nozzles downstream of the control valve are clear;

(ii) all piping is properly secured;

(d) for water monitors;

(i) the operating positions for each fixed monitor will be readily accessible in the event of a fire in the parts of the installation they are intended to protect; and monitors in exposed positions can be effectively deployed in adverse weather conditions;

(ii) all local, remote, manual and automatic controls function as intended;

(iii) where provided, each portable monitor can be readily relocated, secured and coupled up to its water supply main.

(e) for water mains including fittings and valves;

(i) the piping fittings and valves have been satisfactorily hydraulically pressure tested in accordance with the following:

Piping Material	**Test Pressure** (kg/cm^2) (At any point in the main)
Steel	W.P. $\times$ 1.5
Copper/Nickel	W.P. $\times$ 1.3

where W.P. is the maximum working pressure which can be generated at that point;

(ii) subject to the Surveyors being satisfied with the above, the system has sustained, after installation, the maximum pressure attainable by the pumps which can be connected to the system;

(iii) the operating position of each isolating valve is readily accessible;

(iv) any pressure relief devices operate at the set pressure;

(v) the response and stability of the system as a whole, i.e. pump units and water mains, is satisfactory. For this purpose suitable water test outlets should be provided at convenient positions at the various principal levels of the installation. At least one such outlet should be provided at each level, having a bore equivalent to the supply to the largest single water demand at that level. Starting with the system in its normal operational condition such outlets should be operated, as considered appropriate, to simulate in-service conditions, demonstrate the response and stability of the system and ensure that sufficient pressure is developed at the various levels;

(vi) the provisions made to prevent freezing are adequate and, if of the 'trace heating' type, are operational;

(vii) piping is properly secured and supported;

(viii) pressures developed in the main are such that hand-held equipment may be handled safely.

Subsequent Examinations

(a) As for (b) (ii), (c) (i) and (iii), (d) (ii) and (e) (iii);

(b) each pump unit to be run for a period of at least 2 hours under full load;

(c) establish that no unauthorised modifications have been made.

3.6 **Automatic Sprinkler and Fire Detection Systems**

A sprinkler system capable of detecting a fire in any accommodation space and operating automatically to protect any such space when a fire is present is required on all manned installations. Audible and visual indication that a sprinkler has come into operation should be provided at the control point and at another place which is continuously manned should the control point be unmanned at any time. The visual indication should be capable of giving the location of the section of the sprinkler system that has come into operation.

For the purposes of this section accommodation spaces are 'any room used for eating, sleeping, cooking or recreation, or as an office, sick bay, laundry room or locker room, any corridor giving access to any of these rooms, and any store room in the vicinity of any of these rooms' and applies to all accommodation spaces whether or not they are in the main recognised living area or quarters block of the installation.

The sprinkler system should be fed from a main which is connected to a pump, where the pump is:

(i) remote from any accommodation space;

(ii) connected to a source of power which is remote from any accommodation space; and

(iii) capable, once actuated, of operating automatically for at least 4 hours; and

(iv) capable of maintaining a supply of water to the system at a pressure sufficient to enable it to operate efficiently.

Sprinkler heads should normally be of the frangible bulb type. Sprinkler heads operated by other means may be accepted where it can be demonstrated that they are no less efficient or reliable than sprinkler heads of the frangible bulb type. The sprinkler heads should come into operation within the temperature range from 68°C to 79°C, except that in locations such as cooking areas where high ambient temperatures might be expected the temperature rating may be increased to not more than 30°C above the maximum deck-head temperature. Sprinkler heads should normally be placed in an overhead position and spaced in a suitable pattern to maintain an average application rate of not less than 5 litres per square metre per minute over the nominal area covered by the sprinklers. Where, due to structural features, sprinklers mounted in an overhead position would not provide effective coverage then other arrangements must be made. In cooking areas the discharge from sprinkler heads should be prevented from impinging directly on to equipment used for heating cooking oil or fat, e.g. by the use of deflector plates or suitable siting of sprinkler heads.

Sprinkler protection need not be provided in ceiling voids where the construction complies fully with the requirements for structural fire protection and there is not equipment or fittings within the voids which presents a fire hazard. Otherwise sprinkler protection is only required where the depth of the void exceeds 300 mm.

The system should be divided into sections in accordance with the configuration of the accommodation space. Normally in multi-tiered accommodation there should be a minimum of one section to each tier. In special instances a single section covering two tiers may be accepted. Section piping should be suspended from structural members. To facilitate in-service maintenance or replacement of systems protecting multi-tiered accommodation, means should be provided whereby a single

TABLE 3

Water Supply	Special Provision
(i) Fresh water supply; sufficient for at least 4 hours operation.	An additional supply from a pressurised fire main or deluge main should be provided but need not have automatic change over.
(ii) Fresh water supply; sufficient for at least 1 hour's operation.	Automatic changeover to supply from a pressurised fire main or deluge main or automatic start-up of dedicated sprinkler pump. N.B. In each case the change over back-up facility should be such as to ensure an uninterrupted flow of water to the sprinkler system.
(iii) Pressurised fire main or deluge main (wet).	Automatic changeover to supply from fire main or deluge main upon drop of pressure in sprinkler system.
(iv) Dedicated sprinkler pump drawing from the sea and arranged for automatic start-up and supply to sprinkler system.	A dedicated fresh water pressure tank so arranged that water can automatically be supplied to keep any sprinkler in the system operating efficiently for at least 4 minutes. Automatic start up of and changeover to supply from pump upon drop of pressure in the system.
(v) Unpressurised fire main or deluge main or dedicated sprinkler pump not arranged for automatic start-up.	A dedicated fresh water pressure tank so arranged that water can be supplied to keep any sprinkler head in the system operating efficiently for at least 10 minutes without supplementing. Manual or automatic changeover to fire main or deluge main supply and remote start-up of fire pumps and operation of associated suction and discharge valves; remote control to be strategically located preferably at the control point.

section may be readily isolated without affecting the operational readiness of the remainder of the system.

The standing charge in the system should normally be fresh water and means should be provided to indicate at some convenient location the pressure of this charge and, where applicable, the pressure in the fire main or deluge main. Should the pressure drop below preset limits then suitably clear and distinct visual and audible alarms should register simultaneously at the control point and additionally at the alternative location when the control point is unmanned.

The water supply arrangement to the system should be capable of maintaining sufficient pressure at the level of the highest sprinkler head to ensure a continuous output of water, for at least 4 hours, at the required application rate for the simultaneous coverage of the maximum area enclosed by approved A and B-Class fire divisions or an area of 280 m^2, whichever is the smaller. The source of water supply together with any pumps, pressure vessels and associated power sources should be located outwith the accommodation spaces. The typical water supply arrangements shown in table 3 would, subject to the special provisions listed, be considered acceptable.

Normal provisions should be made to enable the system to be tested without detracting from its operational efficiency or disrupting the routine operation of the installation.

Additionally, plan appraisal to verify compliance concerning the following will be required by the Society's Engineering Departments:

(a) construction of any associated pressure vessels and fittings;

(b) power sources (including changeover arrangements, electric cabling and switchgear, associated control circuitry).

The scope of initial and subsequent surveys by the Outport Surveyors should generally cover the following:

Initial Examination

(a) to establish that the system has been installed in accordance with approved plans;

(b) to establish that piping has been satisfactorily hydraulically pressure tested;

(c) to conduct a suitable simulation test to ensure that water supply arrangements operate as intended be they automatic or manual;

(d) to conduct a suitable simulation test to ensure that the water supply arrangements have sufficient capacity to meet the water requirements (a flow measuring device and pressure gauge should be provided for this test);

(e) to establish that all associated audible and visual alarms function as intended. Alarms should be initiated by simulating operation of a single sprinkler head in various parts of the accommodation spaces;

(f) to establish that all associated instrumentation functions efficiently;

(g) to establish that sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

(a) as for (c), (d), (e), (f) and (g) above;

(b) an internal inspection at selected points in the system where sea water is used as the standing charge;

(c) to establish that no unauthorised modifications have been made.

3.7 Fixed Fire Extinguishing Systems

A fixed fire extinguishing system is required for each of the following:

(a) the control point (as previously defined);

(b) all spaces containing;

(i) internal combustion machinery having in aggregate a power of 750 kW or more;

(ii) oil or gas fired boilers, heaters or incinerators having a thermal rating of 75 kW or more;

(iii) any equipment through which fuel for prime movers, boilers or fixed processes is pumped at a pressure in excess of 10 kg/cm^2.

The media acceptable for the protection of these spaces are:

(i) halogenated hydrocarbons, bromotrifluoromethane (Halon 1301) and bromochlorodifluoromethane (Halon 1211);

(ii) carbon dioxide (CO_2);

(iii) foam;
N.B. Foams are not suitable extinguishing agents for fires involving gases, liquefied gases with boiling points below ambient temperatures such as butane, methane etc. or cryogenic liquids.

(iv) water (in pressurised spray).

Where in a space the principal fire hazard or equipment necessitating the provision of a fixed fire extinguishing system is itself within an enclosure which is of such construction as to provide sufficient and suitable containment for the extinguishing medium then the coverage or extent of the system may be restricted to the enclosure, e.g. main generator acoustic/fire hoods within the main power generation module. Where either a CO_2 or Halon system is used to protect a space in which a flammable atmosphere may develop and where, under emergency conditions, release of the system into the space for purposes other than fire extinguishing is contemplated, then, operating procedures should take account of the possibility of generation of static electricity during release.

The general requirements for each type of fixed fire extinguishing system, except water spray, should comply with the applicable section of the Rules and Regulations for the Classification of Ships, Part 6, Chapter 4. Required salient features for offshore installations not covered by these Rules are as follows:

Sufficient and suitable means should be provided at the operating point(s) of any fixed fire extinguishing system to indicate:

(i) the operational status of the system; and

(ii) whether or not the system has been operated.

Where in the case of an auto/manual operated system facilities exist to temporarily 'lock-off' or de-activate the automatic function then operational procedures should dictate that no such action should be taken without prior permission from a person in authority.

On large installations, having a number of spaces each protected by a fixed fire extinguishing system, means should be provided whereby such systems can be operated from the control point.

Where appropriate the system should have self-monitoring potential enabling detection of electrical faults which may affect the operational efficiency of the system. Detection of any such fault should register by suitable audible alarm, distinct from background noise, and clear visual alarms at the control point and additionally in the case of normally manned installations at another place on the installation where someone is present at all times when the control point is unmanned.

Where systems are arranged for remote and/or automatic release they should also be capable of local manual operation.

Whereas on ships automatic operation of gaseous fire extinguishing systems is not acceptable, such systems can be accepted on offshore installations subject to the following requirements:

(i) Automatic release into spaces in which personnel may be present; for such spaces only Halon 1301 may be accepted subject to full compliance with (a), (b), (c) and (d) as follows:

(a) the space protected should preferably be on one working level and on the same level as the access. More than one working level may be included provided there is access on each level;

(b) the size of the space and arrangements of access and equipment should be such that escape from anywhere in the space can be effected in not more than 10 seconds;

(c) the operation of the system should be signalled both visually and audibly outside each access to the space and at the control point for the installation;

(d) a notice indicating that the space is protected by an automatically operated fire extinguishing system should be displayed outside each access.

(ii) Automatic release into spaces to which personnel do not normally have access; for such spaces only Halon 1211 or Halon 1301 may be accepted.

Automatic release may be achieved by electrical, hydraulic, pneumatic or electro-explosive means.

Where systems are arranged for automatic release upon detection of a fire situation, then suitable precautions should be taken to prevent release of the system as a result of a spurious operation of fire detectors.

Where a Halon 1211 or Halon 1301 fixed fire extinguishing system is arranged for automatic injection into a space then visual indication should be provided at each access to the space and at the control point indicating the operational status of the system.

The requirements for fixed water spray systems are that the system should be divided into sections, the control valves of which could be operated from easily accessible positions outside the spaces to be protected and which will not be readily cut off by an outbreak of fire. The water supply for the system should be put automatically into action and may be from dedicated pump(s) or from a pressurized fire water system of sufficient capacity. The water supply should be capable of simultaneously supplying at the necessary pressure all sections of the system in any one space. The water supply and associated controls should be installed outside the space or spaces to be protected. It should not be possible for a fire in the space or spaces protected by the system to put it out of action. The piping system should be of a corrosion resistant material, due regard being given to the heat resistance of the material used and the possibility of its being subjected to very high temperatures prior to the introduction of water. The number and arrangement of the nozzles should be such as to ensure an effective distribution of water over the areas to be protected. Nozzles should be fitted above areas over which oil fuel is liable to spread and also above other specific fire hazards in the spaces. Typical water application rates dependent on the fire risk involved are shown in table 4.

Water spraying nozzles should be of a type suitable for extinguishing burning oil and precautions should be taken to prevent the nozzles from becoming clogged by impurities in the water or corrosion particles from the system pipework. Where applicable the system should include mobile sprayers ready for immediate use in the firing area of the boiler or in the vicinity of the oil fuel unit.

The scope of initial and subsequent surveys by the Outport Surveyors should generally cover the following:

TABLE 4

Fire risk	Application rate in litres per metre² per minute
Boiler fronts or roof firing areas; oil fuel units; centrifugal separators (not oil water separators); oil fuel purifiers and clarifiers; oil fuel pressure pumps.	20
Hot oil fuel pipes near exhaust pipes or similar heated surfaces on main or auxiliary diesel engines.	10
Machinery module floors; tank top areas; oil tanks not forming part of the unit's structure.	5

Initial Examination

(a) to establish that all equipment covered under this Section has been installed in accordance with approved plans;

(b) to establish that all distribution piping nozzles or applicators are clear;

(c) to establish that all distribution piping is properly secured;

(d) to verify that all cylinders, tanks, gas manifolds and piping subjected to pressure have been satisfactorily hydraulically pressure tested;

(e) to establish that all associated operating controls, distribution valves, alarms, instrumentation, indicating devices, safety devices function as intended;

(f) to verify that all cylinders containing gaseous media and driving gas or tanks containing foam concentrate have been correctly charged;

(g) to establish that sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

As for (b), (e), (g) and also to verify that all cylinders containing gaseous media or tanks containing foam concentrate are correctly charged; additionally to establish that no unauthorised modifications have been made.

3.8 Helicopter Landing Area Equipment

A fixed foam system capable of discharging foam solution onto the landing area is required. The minimum capacity of the system should be based on a foam solution application rate of not less than 6 litres/metre²/minute for a period of not less than 5 minutes over an area equal in size to $0.75L^2$, where L is the overall length of the largest helicopter which the landing area has been designed to accommodate. The foam compound used should be of the low expansion type with a maximum expansion ratio of 12:1 and be compatible with the dry powder used in the portable extinguishers required at the helideck. Both protein and AFFF (aqueous film forming foam) concentrates would be acceptable for the type of fire expected at the helideck.

The method used for delivering the foam solution can be by monitors, branch pipes, or a piping system with foam nozzles. Whatever the method used due account should be taken of any prevailing wind conditions expected during helicopter operations. The water supply should normally be taken from the installation's fire main. The foam system should, in addition to foam, be capable of discharging water only.

The following portable fire fighting equipment is required in addition to the fixed foam system:

(a) one or more dry powder fire extinguishers having an aggregate capacity of not less than 45 kg; and

(b) either:
  (i) one or more carbon dioxide fire extinguishers with applicators having an aggregate capacity of not less than 18 kg; or
  (ii) one or more halogenated hydrocarbon fire extinguishers with applicators having an aggregate capacity of not less than 12 kg.

Two sets of fireman's equipment are to be kept at a place which is readily accessible from the helicopter landing area.

The scope of initial and subsequent surveys by the Outport Surveyors should generally cover the following:

Initial Examination

To establish that:

(a) the system has been installed in accordance with the approved plans;

(b) under operating conditions, using foam and water during realistic wind conditions, the foam system operates satisfactorily. During this test (for which the Owner should allocate any test personnel required) the following should be established where appropriate:
  (i) the foam throw in metres of each applicator (with no other applicator operating) under maximum flow conditions:
  (ii) the quantity of concentrate in litres/minute taken by each applicator and the water pressure in bars available at the applicator;
  (iii) that under the prevailing wind conditions the foam cascade from the system, when discharging the minimum quantity of foam required, can be brought to bear on any part of the landing circle;
  (iv) that the quality of foam formed is satisfactory;
  (v) that all associated controls and instrumentation function as intended;

(c) satisfactory and suitable means of access are provided to the operating stations for each applicator;

(d) the applicators (including associated services) can be rapidly deployed and manipulated. Applicators arranged for remote control should also be tested under local control;

(e) satisfactory and suitable means of access are provided to the stowage locations of portable and non-portable extinguishers and that such equipment can be rapidly deployed;

(f) sufficient and suitable operational and maintenance instructions have been provided.

Subsequent Examinations

(a) to ensure that the operational status (by functional tests if considered necessary) of the foam system and extinguishers are at a maximum;

(b) the quality of the stored foam concentrate is within manufacturers specifications;

(c) no unauthorised modifications have been made.

3.9 **Portable Fire-fighting Equipment**

Hand portable fire extinguishers (of weight not exceeding 23 kg) and wheeled trolley units above this weight are required to be distributed throughout the installation such that at least one extinguisher, of a type suitable for fighting a fire of the type most likely to occur in that part of the installation, is readily accessible from any part of the installation. In accommodation spaces this should be one extinguisher adjacent to every exit and at least one other extinguisher on each level. In other spaces extinguishers should be positioned such that any person inside will, at no time, be more than 10 metres from a portable fire extinguisher.

A description of the types of extinguisher suitable for use appears in the LRTA Paper No. 1, Session 1974-75 and remains applicable for offshore installations. However the sizes suitable for use should generally be as follows:

(a) portable fire extinguishers (other than carbon dioxide or halon fire extinguishers) should if they are of a type discharging fluid, have a capacity of not more than 13.5 and not less than 9 litres;

(b) carbon dioxide fire extinguishers should have a capacity of not less than 3.2 kilogrammes;

(c) dry powder fire extinguishers should have a capacity of not less than 4.5 kilogrammes of dry powder;

(d) when bromochlorodifluoromethane ($C\,Br\,Cl\,F_2$, BCF or Halon 1211) or bromotrifluoromethane ($C\,Br\,F_3$, BTM or Halon 1301) fire extinguishers are provided on offshore installations they should contain not less than 0.5 kilogramme and not more than 7.3 kilogrammes of the fire extinguishing medium, the upper limit being in order to keep the concentration of the discharged medium below 5% in small spaces.

Because of the deterioration to which the ingredients of foam-making liquids are liable at temperatures of 38°C or over, foam fire extinguishers should be kept in as cool a place as possible. Additionally, they should not be stowed in a position where the ambient temperature is liable to fall below 0°C. Dry powder and CO_2 extinguishers are generally suitable for use at temperatures down to −30°C but the latter type should not be exposed to corrosive conditions or to a temperature exceeding 60°C. Halon extinguishers are generally suitable for use at temperatures down to 0°C but should not be exposed to corrosive conditions or to a temperature exceeding 55°C. The extinguishing media provided adjacent to any given fire risk should be suitable for the type of fire risk involved.

A minimum of four sets of fireman's equipment are required for each installation, two of which should be located near the helideck as previously stated in Section 3.8. Details of these outfits appear in the LRTA Paper No. 1, Session 1974-75. Although the Society's Ship Rules at that time did not require protective clothing they do now. The personal equipment detailed in 6.4.8.1.1 (a) of these Rules will also be acceptable for use on offshore installations.

A fire blanket should be provided for each galley on an offshore installation and kept at a place which is readily accessible to anyone in the galley in a container which is marked with clear instructions for use.

3.10 **Plans Required for Appraisal**

Plans and calculations should be submitted to HQ for appraisal concerning compliance with the foregoing and should clearly show the following:

Fire and Gas Detection Systems and Alarm Systems

1. The location of each fire and gas detector head, manual alarm, public address system, loud speakers and control stations on general arrangement drawings.
2. Logic diagrams showing the sequence of events when each system is activated.
3. Full details of the type of equipment proposed and its suitability if to be used in hazardous areas.
4. Location of main and emergency power supplies.

Firefighting Systems

1. The location of the fire main fire-pump-units, fire main systems, fire hydrants, hose reels, isolating valves, water deluge systems, water sprinkler systems, CO_2 systems, foam systems, dry powder systems, Halon systems, portable and non-portable fire extinguishers, and fireman's outfits on a general arrangement drawing; the capacity and extinguishing media of the fire extinguishers.
2. The materials of the fire mains, valves, etc.
3. Location of fire pump units and their power sources to ensure that a fire in any one compartment will not impair the fire water supply.
4. Details of each fire extinguishing system showing the method of storage or supply of the extinguishing medium, distribution to the protected spaces and areas, method of release, control and directional valves, pipework, pressure vessels and gas cylinders.
5. Calculations for each extinguishing system to show that each part of the platform is adequately protected at the required application rate of extinguishing medium and that the source of extinguishing medium can maintain its supply at the required application rate for the required duration.

4. MOBILE INSTALLATIONS OUTSIDE U.K. WATERS

The Society first published Rules for the Construction and Classification of Mobile Offshore Units in 1972. These Rules, apart from the fire hazards of unique spaces concerned with drilling operations, essentially required such units to comply with the published Rules for ships, the only notable differences being a requirement for all materials entering into the structural fire protection to be non-combustible and the minimum delivery from at least two fire hoses being 162 litres per minute at 3.0 kg/cm^2 water pressure (for ships the capacity was unspecified and the pressure varied from 2.8 to 3.2 kg/cm^2 depending on gross tonnage). Consideration was also given to the requirement for a water storage tank in those cases where the combination of the units height and installed pumps could not meet those requirements. The minimum capacity had to be adequate for at least 15 minutes operation at the required delivery rate and pressure.

International recognition of the hazards associated with drilling units was not established until IMO Resolution A414 (X1), Code for the Construction and Equipment of Mobile Offshore Drilling Units (MODU Code), was adopted on 15th November 1979 although the Maritime Safety Committee (MSC) of IMO had made recommendations on fire safety some years before. The MODU Code was developed with the intent to provide an international standard to facilitate international movement and operation of such units and provide a level of safety equivalent to that required for ships engaged on international voyages by the International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and the International Convention on Load Lines, 1966.

The Society's Rules have been under review for some years and, at the time of writing, new Rules for mobile offshore units are expected to be published in January, 1983. The new Rules are generally based on the IMO MODU Code and IACS Unified Requirements. However the Society has, in addition to

drilling units, recognised the hazards associated with 'service units' and included these in the scope of application. Service Units are those units similar to the various types of drilling units but intended for support operations not directly associated with exploration or exploitation of sub-sea mineral resources, examples being accommodation units and those equipped to deal with diving or fire emergencies. Thus in addition to the Class notation ✠OU 100 A1 some units may also have a Firefighting Unit notation and an entry made in the Register Book for the installed diving system (see Section 6 for Firefighting Units and Section 5 for Classed Diving Systems).

Mobile offshore drilling units operating in waters other than those of the U.K. may be required to comply with Regulations prescribed by the Administration concerned, e.g. Norway and the Regulations of the Norwegian Maritime Directorate (NMD). Some countries require compliance with the MODU Code whilst others have not yet passed any legislation concerning such units and only Classification is required by the Owner. The requirements of the U.K. apply equally to all fixed and mobile installations and have been given in Section 2.

Recognising the possibility that a drilling unit may be required to work in U.K. or Norwegian waters on completion of an operation in other areas for which the unit was originally intended, some Owners request the Society to carry out plan appraisal and surveys during construction to verify compliance with the applicable national Regulations. The Society has not been authorised by either the U.K. or Norwegian Administrations to carry out this work on their behalf but can issue a Statement of Compliance to the Owner thus avoiding any serious deficiencies and expensive modifications when the unit is presented to the Administrations concerned for certification purposes at a later date. The U.K. requirements have been covered in foregoing sections.

4.1 Classification Requirements

The fire hazards associated with petroleum processing on a fixed platform are not present on a mobile unit and the associated hazardous areas are thus restricted to those areas where, due to the possible presence of a flammable atmosphere arising from drilling operations, the use without proper consideration of machinery or electrical equipment may lead to a fire or explosion. Both the MODU Code and the Society's Rules, except for the fire integrity of decks and bulkheads separating hazardous areas from others, require the fire protection of accommodation spaces, service spaces and control stations to be of a standard equal to that which will be required by the Amendments to SOLAS 1974 when they become mandatory, probably in 1984. These are shown in tables 5 and 6.

The requirements for fire pumps, fire mains, hydrants and hoses are similar to those for ships except that the working pressure is required to be not less than 3.5 kg/cm^2 when operating any two hydrants and hoses with 19 mm nozzles (3.2 kg/cm^2 for ships above 1000 tons gross) and at least one of the required pumps is to be dedicated for firefighting duties and be available for such duty at all times. Fire extinguishing systems using water spray, CO^2, Halon 1301 or foams are required for machinery spaces and spaces containing fired processes.

An automatic fire detection and alarm system should be provided in all accommodation and service spaces, with sufficient manual call points located throughout the remaining spaces on the unit. A fixed automatic gas detection and alarm system should be provided to continuously monitor all enclosed spaces where an accumulation of flammable gas may be expected to occur. On detection, audible and visual alarms should be given at the control station and the location of the accumulation indicated. At least two portable gas monitoring devices should also be provided.

Helicopter landing area equipment as described in Section 3.8 should be provided.

The Society's Rules do not require a deluge system for the protection of the drill floor or the well test equipment as required by the U.K. Administration, however, in the authors' experience, few mobile offshore units are presented for Classification without such systems.

Windows fitted in accommodation house fronts facing the drill floor are required to be of a non-opening type with permanently attached steel shutters. Alternatively, shutters may be omitted provided an external water spray is installed.

TABLE 5. FIRE INTEGRITY OF BULKHEADS SEPARATING ADJACENT SPACES

Spaces	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations (1)	A-0$_d$	A-0	A-60	A-0	A-15	A-60	A-15	A-60	A-60	*
Corridors (2)		C	B-0	B-0 A-0$_b$	B-0	A-60	A-0	A-0	A-0	*
Accommodation spaces (3)			C	B-0 A-0$_b$	B-0	A-60	A-0	A-0	A-0	*
Stairways (4)				B-0 A-0$_b$	B-0 A-0$_b$	A-60	A-0	A-0	A-0	* *
Service spaces (low risk) (5)					C	A-60	A-0	A-0	A-0	*
Machinery spaces of Category A (6)						* a	A-0$_a$	A-60	A-60	*
Other machinery spaces (7)							A-0$_a$ c	A-0	A-0	*
Hazardous areas (8)								—	A-0	—
Service spaces (high risk) (9)									A-0$_c$	*
Open decks (10)										—

TABLE 6. FIRE INTEGRITY OF DECKS SEPARATING ADJACENT SPACES

Space Below ↓ Space Above →	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Control stations (1)	A-0	A-0	A-0	A-0	A-0	A-60	A-0	A-0	A-0	*
Corridors (2)	A-0	*	*	A-0	*	A-60	A-0	A-0	A-0	*
Accommodation spaces (3)	A-60	A-0	*	A-0	*	A-60	A-0	A-0	A-0	*
Stairways (4)	A-0	A-0	A-0	*	A-0	A-60	A-0	A-0	A-0	*
Service spaces (low risk) (5)	A-15	A-0	A-0	A-0	*	A-60	A-0	A-0	A-0	*
Machinery spaces of Category A (6)	A-60	A-60	A-60	A-60	A-60	* [a]	A-60	A-60	A-60	*
Other machinery spaces (7)	A-15	A-0	A-0	A-0	A-0	A-0 [a]	* [a]	A-0	A-0	*
Hazardous areas (8)	A-60	A-0	A-0	A-0	A-0	A-60	A-0	—	A-0	—
Service spaces (high risk) (9)	A-60	A-0	A-0	A-0	A-0	A-0	A-0	A-0	A-0[c]	*
Open decks (10)	*	*	*	*	*	*	*	—	*	—

Notes: To be applied to both tables 5 and 6 as appropriate.

[a] Where the space contains an emergency power source or components of an emergency power source that adjoins a space containing a ship's service generator or the components of a ship's service generator, the boundary bulkhead or deck between those spaces should be an A-60 Class division.

[b] Stairways which penetrate only a single deck should be protected at least at one level by A or B-Class divisions and self-closing doors so as to limit the rapid spread of fire from one deck to another. Personnel lift trunks should be protected by A-Class divisions. Stairways and lift trunks which penetrate more than a single deck should be surrounded by A-Class divisions and protected by self-closing doors at all levels.

[c] Where spaces are of the same numerical category and superscript d appears, a bulkhead or deck of the rating shown in the tables is only required when the adjacent spaces are for a different purpose, e.g. in category (9). A galley next to a galley does not require a bulkhead but a galley next to a paint room requires an 'A-0' bulkhead.

[d] Bulkheads separating the navigating bridge chartroom and radio room from each other may be 'B-0' rating.

* Where an asterisk appears in the tables the division is required to be of steel or equivalent material but is not required to be of A-Class standard.

4.2 Norwegian Maritime Directorate Requirements

The NMD separates offshore units into 'drilling vessels' and 'drilling platforms'.

Drilling vessels are those with a normal ship form, usually with the drilling tower amidships above a moonpool. These are required to comply with the NMD Regulations for Ships, except that the working pressure of the fire main is to be not less than 5 kg/cm^2 with any two hydrants and hoses with 12 mm nozzles in operation. The NMD requirements concerning fire aspects for ships are similar to the Society's Rules for cargo ships.

For drilling platforms of other than ship form the NMD requires a water storage tank to be provided where the combinations of the units height and pump characteristics could not meet the pressure requirements of at least 5 kg/cm^2 in the fire main when any two hydrants and hoses with 12 mm bore nozzles are in operation. The tank should have a capacity sufficient for 15 minutes efficient operation of the fire main. At least two independently powered fire pumps are required each with a capacity of not less than 50 m^3 per hour. No upper limit is specified.

Fire extinguishing systems are required on both drilling vessels and drilling units for spaces containing internal combustion machinery above 500 b.h.p. and fired processes. For the protection of helicopter landing areas, two fixed low expansion foam units coupled to the fire main are required. The total capacity is to be not less than 1250 litres per minute but no reference is made to the size of the area over which the foam is to be applied.

The structural fire protection requirements for drilling vessels and platforms are similar to the Society's Rules for cargo ships, except that accommodation spaces situated next to spaces presenting a fire risk such as engine rooms, mud pit rooms, galleys and other rooms containing combustible materials should be separated from such spaces by A-60 Class divisions. This also applies to spaces containing sources of emergency power and control stations adjacent to high fire risk spaces.

4.3 **Plans Required for Appraisal**

The scope of plan appraisal will encompass other regulations than the Society's Rules and Owners' or Builders' requirements should be made known as early as possible. For all mobile offshore units plans and calculations to be submitted for appraisal should provide the following information:

STRUCTURAL FIRE PROTECTION

1. A general arrangement drawing showing the location and rating of each fire wall. The purpose of the spaces enclosed by the fire walls should be stated.
2. Construction details of each type of fire wall, including materials of construction, density and thickness of insulation, method of attachment to main structure and interpanel attachment.
3. Protection of fire walls in way of penetrations by ventilation ducts, doors, pipes and cables and heat bridges.
4. Certificates of Approval or suitable fire test data in respect of the fire resistance ratings of designated fire divisions (both internal and external), doors, shutters, ceiling constructions, etc. Approval authorities may be Lloyd's Register or in some cases the national authorities in the country of manufacture.
5. Layout of escape routes.

FIRE AND GAS DETECTION SYSTEMS AND ALARM SYSTEMS

1. A general arrangement drawing showing the location of each fire and gas detector head, manual alarm, public address system, loud speakers and control stations
2. Logic diagrams showing the sequence of events when each system is activated.
3. Full details of the type of equipment to be used and suitability if used in hazardous areas.
4. A plan showing the location of main and emergency power supplies.

FIREFIGHTING SYSTEMS

1. A general arrangement drawing showing the location of the main fire pumps, fire main systems, fire hydrants, hose reels, block valves, water deluge and sprinkler systems if fitted, CO_2 systems, foam systems, dry powder systems, Halon systems, portable and non-portable fire extinguishers, and fireman's outfits. The capacity and extinguishing media of the fire extinguishers should be stated.
2. Details of the materials of fire mains, valves, etc.
3. A plan showing the fire pumps and their power sources which are to be so arranged that a fire in any one compartment will not impair the fire water supply.
4. Details of each fire extinguishing system showing the method of storage or supply of the extinguishing medium, distribution to the protected spaces and areas, method of release, control and directional valves, pipework, pressure vessels and gas cylinders.
5. Calculations for each extinguishing system to show that each part of the platform is adequately protected at the required application rate of extinguishing medium and that the source of extinguishing medium can maintain its supply at the required application rate for the required duration.

5. DIVING SYSTEMS

Except for some gravity-type concrete structures where access to the seabed wellheads is possible down one of the supporting legs, diver intervention for the operation of subsea valves is required on most installations. Thus diving systems are common on offshore installations.

The environment of a diving chamber presents special problems concerning fire, the most significant of these being the inability of the divers to retreat to a safe location and the rate of combustion after the onset of fire. Ignition of combustible material in the most common breathing gas mixture of helium and oxygen is more difficult to achieve than in normal atmospheric conditions but once a fire has started in the pressurised chamber the rate of combustion is greater, as also is the case in oxygen enriched atmospheres (OEA's). This however varies with pressure, or 'depth' in diving terms, and at depths of 30 atmospheres with a breathing gas mixture of 4% O_2/96% He combustion is not considered possible. Thus the risk of fire is more likely at near surface depths and all dives, regardless of the working depth, must pass through this stage.

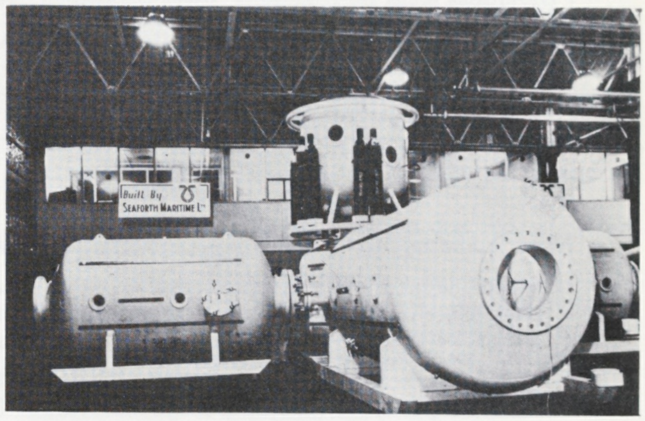


PLATE 5

Deck diving complex

The Society's requirements contained in the Rules for the Construction and Classification of Submersibles and Diving Systems, Part 2, Chapter 1, Section 8.6 state only that 'the exact requirements for fire protection, detection and extinction can only be decided by an appraisal of the plans in each particular case'. Authoritative data from recognised sources in assessing the suitability of the fire protection arrangements for hyperbaric facilities is very limited and the Society's experience has been drawn from published information concerning medical and space facilities where the breathing gas mixtures have been oxygen enriched up to as much as 100% and from the limited testing in diving installations using both compressed air and helium-oxygen mixtures.

The toxicity of gas or dry powder fire extinguishing agents commonly used on ships render these unsuitable for use in a diving chamber and water has been adopted as the most suitable medium. A water application rate of 100 litres/m^2/minute is presently considered adequate where the reference area is taken as a nominal 'floor' located at a height of D/4 in the protected chamber. An internal ring main with spray nozzles is required to achieve an even distribution of water, due consideration being given to the angular orientation of the nozzles to overcome the screening effects of internals such as bunks etc. The nozzle type selected should produce coarse droplets of water since a fog-jet type produces small water particles which tend to remain in suspension and lead to possible drowning of the occupants by inhalation. The normal area coverage by a single nozzle tends to be reduced by pressures higher than atmospheric and good overlaps in the expected spray pattern should be provided.

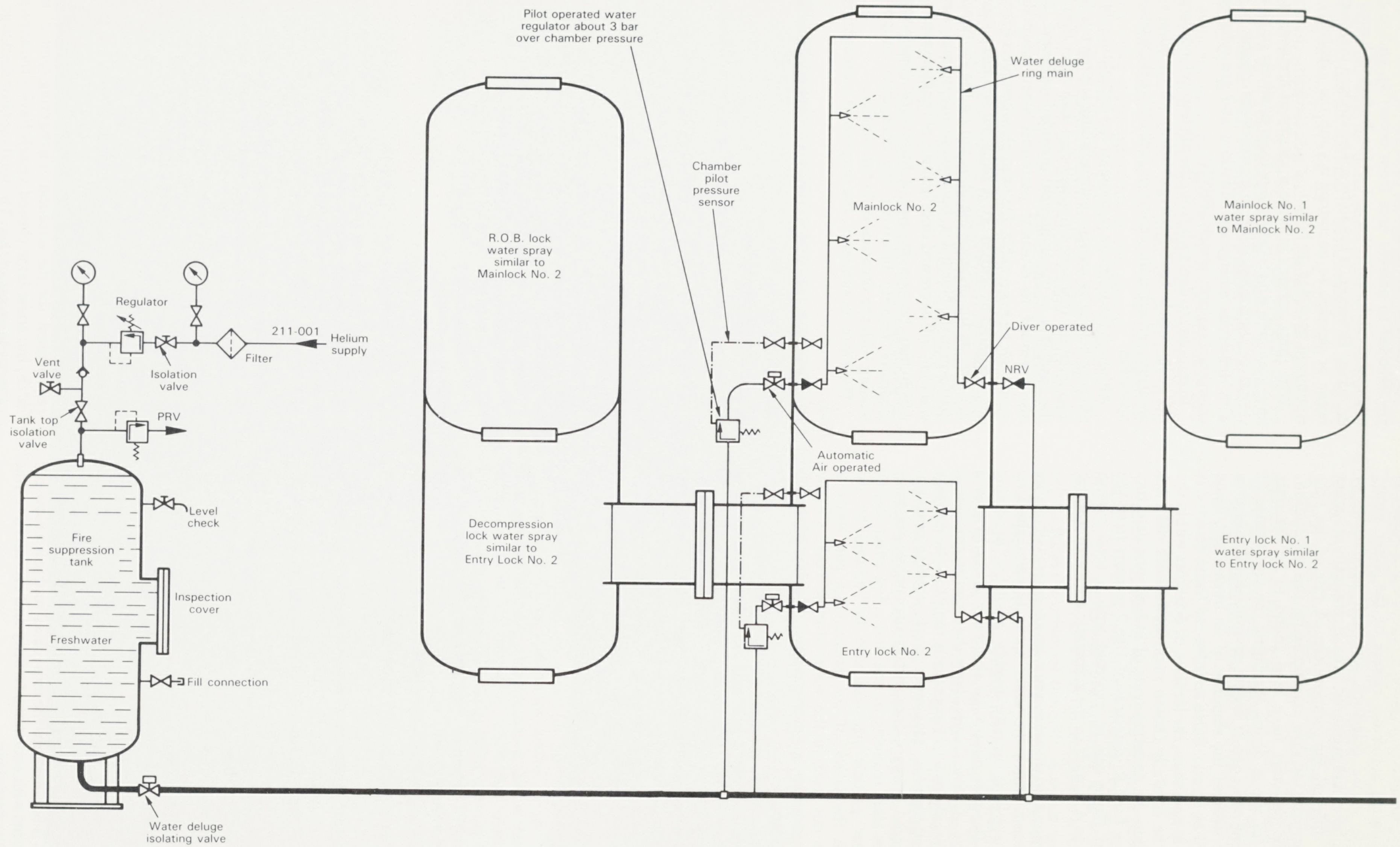


Fig. 5

Diagrammatic arrangement of fire protection system for deck diving chambers

An automatic fire detection system is required and should be capable of initiating automatic release of the water spray. Ionised particle smoke detectors, although satisfactory at surface atmospheres and pressures, behave erratically at higher pressures and different gas compositions. A rate of rise heat detector is inherently too slow in response for this application. Infra-red flame detectors have been found to be the only suitable type for use in diving chambers; the appearance of flames becoming more red at higher environmental pressures aids this type whereas the response of an ultra-violet flame detector would be erratic. Since an infra-red flame detector is 'line of sight' in operation, the location of detectors within the habitat must be carefully chosen such that all fire risks are contained within the detection cone of at least one detector. Response times for I.R. detectors of 1 to 2 seconds from the appearance of flame can be expected with a total system response of 3 to 4 seconds to the automatic release of a water spray.

Figure 5 shows a diagrammatic arrangement of a fire protection system where the water spray is pressurised by helium gas which is usually readily available in diving installations. Pressure control of the water spray to give a nozzle pressure of about 2 bars above the chamber pressure is by a tracking regulator which constantly monitors the pressure in the protected chamber. Maximum nozzle working pressures should not exceed 3·5 bars since with greater nozzle pressures spray particles start reducing in size and a fog effect can be created. Water particle size can also be reduced by the absorption in the water of the pressurising gas where a diaphragm is not used in the water storage tank. Careful consideration should be given to the water solubility of the gas used in these cases.

The introduction of a quantity of water into a chamber will significantly increase the 'depth' and controlled venting will be necessary. This is also likely at an early stage of a fire where the depth may be increased by the release of heat energy from the combustion process. It is thus expected that the Diving Control Technician would be able to take manual control of the automatic fire protection system within 15 seconds of its release and operate the system in short bursts until the fire is extinguished.

A fire will create a concentration of carbon monoxide in a chamber which may be injurious to health, though the incorporation of a carbon monoxide scrubber in the life support system would overcome this. Alternative operating proposals where the divers lock-through to an adjacent chamber and go onto BIBS (built in breathing system) whilst the contaminated chamber is purged or decompressed for repairs would be acceptable.

The following information is required for plan appraisal:

1. General Arrangement showing the layout of the chambers, internal outfit, water spray system and detection system.
2. Details of water spray storage and pressurising arrangements.
3. Details of fire detection and water spray automatic/manual release systems.
4. Hydraulic calculations to verify the water application rate with isometric projections of pipe runs showing pipe sizes and details of nozzle characteristics.

The fire protection requirements for the spaces containing diving systems and their control cabins is dealt with in Section 2.3.

6. FIREFIGHTING UNITS

Offshore installations are vulnerable to a variety of hazards, one of which is fire. Perhaps the most catastrophic is a blow-out fire which burns with enormous ferocity and presents a terrific problem to the firefighter.

The measures discussed in the previous sections of the paper are intended to prevent fires from occurring and to provide equipment on the units themselves for dealing with such fires as do occur. However, it has to be acknowledged that fires could occur or develop to an extent beyond the capability of the equipment provided on board.

With these hazards in mind a variety of firefighting vessels have been built which vary in size from relatively small ships to very large semi-submersible units which are capable of dealing with numerous emergency situations and are referred to as emergency support vessels (ESV's).

In response to demands from the offshore oil industry, Rules for such vessels have been published which offer six class notations reflecting the variety of firefighting ships currently in operation.

Although the ultimate purpose of the firefighting ship in the offshore field is to assist in extinguishing a blow-out fire, it is also intended that such ships will deal with other fires beyond the capability of the equipment provided on board. They are also intended to evacuate personnel where normal means would not be practicable, for example when the surface of the sea is covered by ignited oil. A blow-out will not always result in a fire, as for instance the blow out on the Phillips Ekofisk platform in the North Sea, but even so an extremely hazardous situation will be created since ignition of the flammable vapours which may be present over a huge area could occur with explosive ferocity involving any emergency support vessel dealing with the situation or in the vicinity.

Therefore, in summary, the purpose of a firefighting ship is to:

(i) extinguish fires such as those in accommodating areas;

(ii) fight blow-out fires;

(iii) evacuate personnel;

(iv) transfer expert personnel to deal with emergencies.

Such a unit is however unlikely to be able to extinguish a blow-out fire and its main function is to provide a constant supply of water through monitors in order to save the jacket while other measures are taken to deal with the blow-out and extinguish the fire.

For operations in the offshore environment firefighting units require to be able to accurately project large jets of water over long distances for a considerable period of time, possibly for months, while a secondary well is drilled to enable the blow-out to be plugged. In view of the great heat radiated by a blow-out fire special precautions must be taken to preserve the integrity of the hull and the more so when the unit is required to operate at close quarters.

6.1 Fire Extinguishing

The main firefighting equipment provided on board a firefighting unit are the water monitors. The minimum requirements are set out in the Rules which specify their number, rate of discharge, range and height of trajectory of the jets above sea level.

The trajectory of a jet together with the characteristics of the monitor barrel and nozzle assembly causes a fall-out of water from the jet before it reaches its target. Whilst it is not required, nor possible, that the water arrives at the target in a solid jet, the fall-out area should be relatively small and provide a heavy shower of water over the target area.

Until the need for this type of ship arose there were very few manufacturers in the world who made sufficiently powerful monitors and a great deal of research has had to be made to produce suitable equipment.

A very large pumping capacity is required. The minimum requirement for the notation 'Firefighting Unit 3' is 10,000 m^3/h, but some large classed vessels have a monitor pumping capacity in excess of this. The total monitor discharge capacity

is included in the class notation for the information of users of the Register Book.

The minimum range of the monitors required by the Rules is 150 metres and the jets will have to be maintained on the target in all sea conditions, perhaps for a period of several months. Consequently, dynamic positioning is desirable if not essential.

Since the surface of the sea in the area of operation may be contaminated by oil, the sea suction inlets must be arranged as low as practicable. This will also help to avoid blockage by ice and floating debris.

The monitors must be capable of being activated and manoeuvred vertically and horizontally by remote control from a protected position and must be prevented from damaging the structure of the ship by accidental impingement of the jets which could cause considerable damage.

The Rules require a minimum of three monitors for Firefighting Unit 2 notation and four for Firefighting Unit 3. In fact the large BP and Shell/Esso ESV's have many more, indeed the 'IOLAIR' (BP) has 17 monitors and two fixed water cannons.

When only three or four monitors are fitted they should be positioned as high as possible in order to achieve the maximum length of jet, but when a larger number is provided some of the additional monitors may be sited lower down to enable a better coverage of the target.

A larger than normal number of hydrants are required to be provided along the sides of the vessel, each with a hose and nozzle capable of producing simultaneously a jet and a spray. These are intended for fighting fires at close quarters through a protective spray and also to provide a cooling spray when rescuing personnel from a burning installation.

To enable fire-fighters and rescuers to operate under the expected conditions, eight additional fireman's outfits are required to be carried. A suitable compressor is also required to facilitate recharging the air cylinders of the breathing apparatus.

6.2 Fire Protection

Pederson of the Norwegian Fire Research Laboratory states that a BLEVE can result in a fire ball with a diameter in the order of 200 metres and 'The radiation load will be $10 kW/m^2$ (blisters on human skin after 10 seconds) in a distance of 450 metres from the centre of the ball'. A vessel approaching an unignited blow out situation could be affected by such a BLEVE if ignition occurred.

Further, a blow-out fire may involve large quantities of liquid at high pressure, 200 bars is not unusual with temperatures in excess of 1000°C. It will therefore be appreciated that heat radiated from such a fire could seriously affect a vessel operating in the vicinity. Consequently fire-fighting units are often provided with water spray systems for the cooling of all

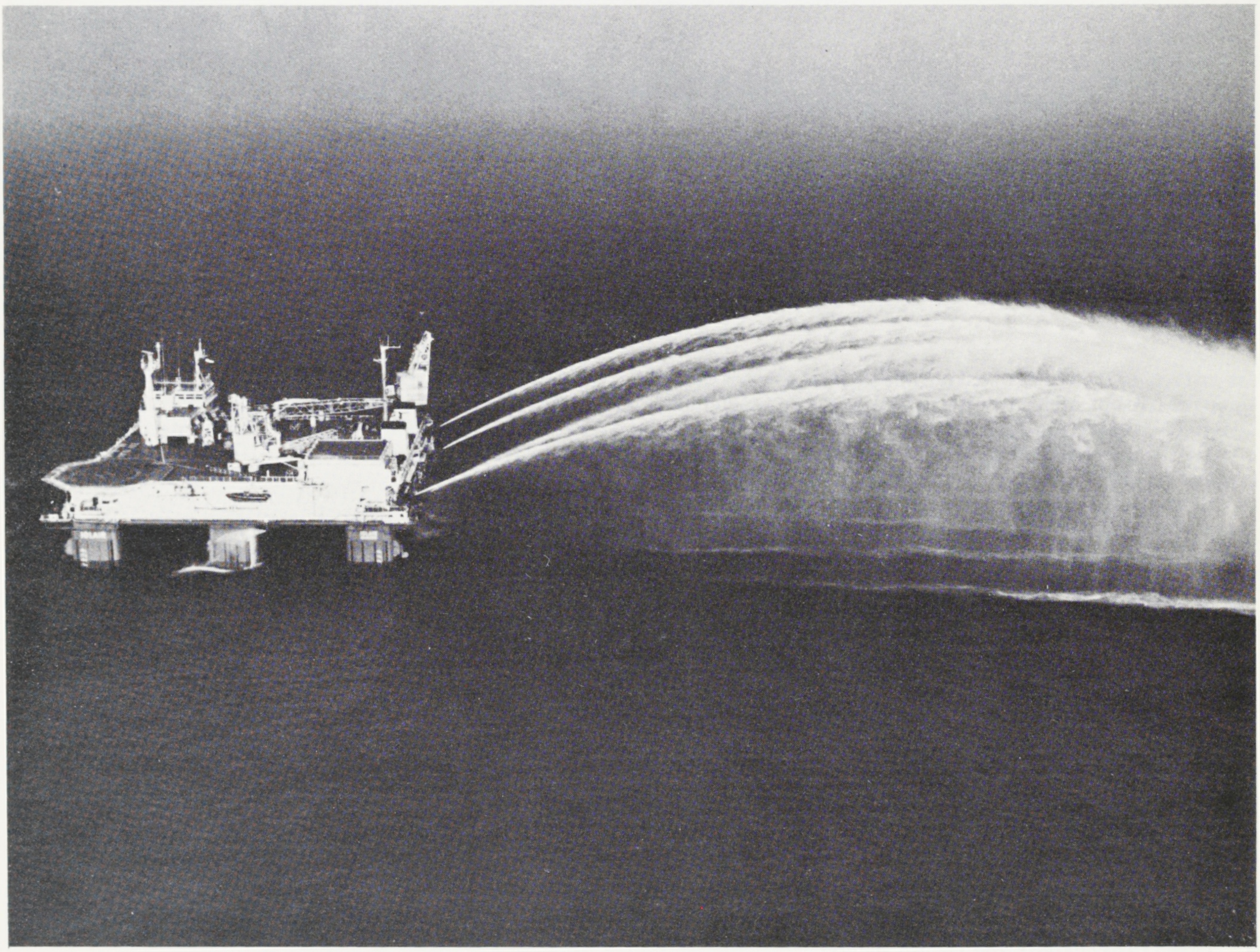


Plate 6

BP/BNOC ESV 'IOLAIR'—showing monitor range

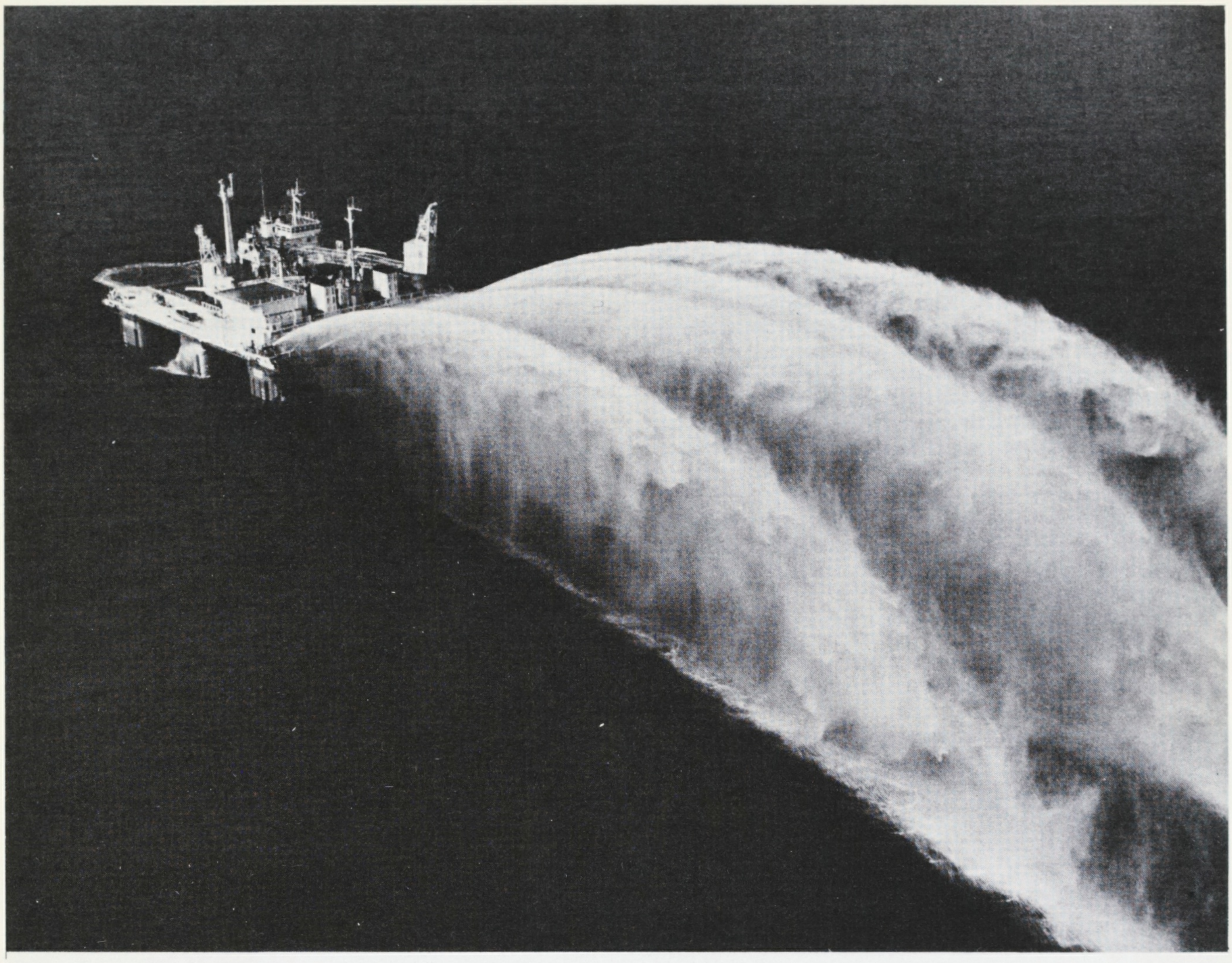


PLATE 7

BP/BNOC ESV 'IOLAIR'—showing water capacity in target area

the surfaces of the vessel which may be exposed to a fire. Such equipment is not obligatory but where it is fitted a suitable addition is made to the class notation.

Water spray systems, where fitted, are required to have a capacity of 10 litres per minute per square metre of the protected area or alternatively 5 litres per minute per square metre where the steel structure is insulated internally to A-60 Class.

6.3 **Lighting**

To facilitate operation at night, two powerful searchlights are required to be fitted to illuminate the target area.

6.4 **Sector Clubs**

Emergency support vessels are extremely costly to build and operate and the industry in the North Sea has formed sector clubs to pool emergency equipment.

There are six of these designated as follows:

1. Red (East of Shetland)
2. Orange (Beryl/Frigg)
3. Yellow (East of Aberdeen)
4. Green (Auk/Ekofisk and Danish waters)
5. Blue (Southern gas fields)
6. Purple (Dutch sector)

In an industry which demands the deployment of very expensive equipment, the geographical sectorisation of the North Sea provides an adequate firefighting capability at a more reasonable cost.

7. CONCLUSION

Fire is a terrible and ever-present hazard to offshore installations. With the rapid exploitation of resources in the North Sea and elsewhere, the construction of the necessary equipment has gone ahead of both national and international legislation.

The rule-making bodies, viz IMO, the national administrations and the classification societies have been developing rules simultaneously and inevitably have come to conclusions which differ in some respects. This has resulted in some confusion and an unnecessary degree of complexity.

The authors hope that their efforts have explained these differences and will help the Society's technical staff to a greater understanding of the subject.

8. ACKNOWLEDGEMENT

The Authors wish to acknowledge the technical advice that was received from Mr. J. H. C. Robertson, Mr. J. M. Bates who checked the draft, Mr. G. Pumphrey and his colleagues who prepared the illustrations, and Mr. J. J. Goodwin for his assistance in editing the proofs.

The Authors also wish to acknowledge the assistance of the following companies who supplied some of the photographs used in this paper:

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Discussion

on the Paper

FIRE PROTECTION, DETECTION AND EXTINCTION IN OFFSHORE INSTALLATIONS

by

Messrs G. Coggon and C. M. Magill

Paper No. 2. Session 1982-83

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

Discussion on the Paper

FIRE PROTECTION, DETECTION AND EXTINCTION IN OFFSHORE INSTALLATIONS

by

Messrs G. Coggon and C. M. Magill

DISCUSSION

From Mr. D. Rennie:

The paper sets out to provide surveyors with information and guidance such that plan approval and field surveys may be more easily accomplished. The authors have been successful in meeting their objective and the paper should be of real value to those involved in this sphere of activity.

Even the layman appreciates the hazards involved in working in this environment and speaks glibly about 'risk'. Those of us who work in the industry acknowledge that risk is high but would the authors care to advise if the risk has been quantified and, if so, what bearing has risk analysis had on rule development?

From Mr. J. Crawford:

The Authors are to be congratulated on producing a very interesting and timely paper which I am sure is going to be used extensively by those involved in offshore installations.

There are, however, a few points I would wish to comment on.

Page 10 Paragraph 3.4

Whilst the headings under items (a) (b) (c) and (d) are referred with specific regard to fire fighting systems, it is considered another item (e) could well be included in this section.

(e) Depressurising/venting of process gas/oil systems.

The authors may have complete faith in the ability of the deluge systems to prevent over-pressure in the various systems due to over-heating, however, I would be much happier if the pressure within the systems was reduced as quickly as possible.

This is a requirement of the API 521 in relation to blowdown/venting of process gas/oil installations which requires depressurisation of the system from working pressure to 7b (100 lbs/ins^2) in approx 15 mins. The depressurisation is taken into account when designing the flare stack in order to ensure that acceptable radiation levels can be obtained in way of the platform during blowdown conditions.

I mention this because whilst typical parts requiring deluge systems are indicated (see page 14.), the deluge systems would not appear to be indicated as a classification item.

Page 8 Paragraph 2.6

Fire tests for flexible hoses

The authors' comments are noted with interest; however it is understood the Society has no specific requirements in this respect other than that they have to comply with national authority requirements.

Would the authors advise if the test as proposed is to be considered as a Society requirement or a national authority requirement? In either case I must express surprise that, since the systems concerned are in the main hydro-carbon orientated, i.e. produced gas/oil and or active contaminated oil based mud systems, to note that the fire test is to be carried out with water as a test medium.

It will be noted that BS 5146 'Fire test for soft seated ball valves' for use in similar systems, also the D.o.T. fire test for flexible hose for use in oil systems, require the tests to be carried out utilizing oil as the test medium. It is appreciated a degree of hazard exists in such tests and this is acknowledged in the various requirements.

In view of the above could the authors advise on what basis the test medium of water is proposed.

Page 11 item (11)

The authors indicate 'safety devices should include features that will permit fail safe operations'; then item (11) 'requires the system to have sufficient stored energy to operate all safety devices at least once'.

I would question these comments on two points.

(1) If one excludes the appropriate classification requirements as applied in the case of the 'domestic' systems i.e. fuel oil systems remote shut off valves, experience would indicate that the drill/production systems on offshore installations are arranged to fail safe on loss of remote operating power. That is, loss of operating power to the control system would result in all essential valves failing open/closed as applicable with resultant shut down of the drill/production system. With the exception possibly of the blow-out preventer shut down system which may require power to lock the valves after closure. This is the reason for the fire test on blow out preventer hydraulic control piping.

(2) With the system as proposed it may well be argued that the piping system itself contains sufficient stored capacity to operate all essential valves at least once. However, possible failure/leakage from the piping system would result in the total control system being rendered inoperable.

Page 11 Paragraph 3.5

It is agreed that the arrangements/location of the fire pumps are to be such that fire in any one location will not result in loss of all fire fighting capability. However what does constitute acceptable arrangements? As previously indicated 'control rooms', 'spaces in which the emergency source of power are located', normally require boundaries to be provided with fire protection i.e. A60 bulkheads. Does the provision of such fire protection have any bearing on the juxtaposition of such equipment. For example, should the required number of pumps be provided in the same area, is this acceptable provided A60 enclosures are provided.

I pose this query from the Classification angle, since on one or two occasions when dealing with area classification drawings it has been noted that the fire pumps/enclosures are situated within the same area, albeit with A60 enclosures. From examination of the plan it would appear that a fire in the vicinity of the pumps could possibly result in both pumps being inaccessible.

I would suggest that such an arrangement would not necessarily be accepted for Classification purposes and attention is drawn to the undesirability of such an arrangement, and confirmation is usually requested that the arrangements have been accepted by the national authority concerned.

It should be appreciated that whilst in accordance with S.I. 611, the C.A. is responsible for ensuring suitability of materials and equipment, the location of the fire pumps would appear to be the responsibility of the national authority.

Page 13

Experience to date has indicated that diesel powered fire pumps are provided on the offshore installations and reference to the requirements of National Fire Protection Association (NFPA) 20 are to be complied with.

With regard to starting arrangements for the fire pump units it is considered that provision should be made for 'black' starting in addition to any automatic starting arrangements.

NFPA 20 requires that not less than 2 air bottles or batteries are to be provided in air and electric starting systems respectively. Each air receiver/battery is to be capable of 6 starts without recharging.

Fuel tanks should be located within the fire pump enclosure and fitted with air and sounding arrangements as required for Classification purposes. Further, the outlet valve should be fitted direct to the tank and be capable of being closed from outside the enclosure.

NFPA 20 requires that a positive suction head be provided at the pump suction and indicates that the outlet valve from the fuel oil tank should be at the level of the fuel pump centre line (see Appendix A. Fig. A.8.4.6. Fuel System for Diesel Engine Driven Fire Pump).

'Sump' fuel tanks should not be provided in conjunction with Diesel powered fire pumps.

Page 15 Piping Materials

It is fair to say that copper nickel alloy piping is now being increasingly used in sea water and fire fighting systems on offshore installations. Recent submissions indicate the increasing use of fabricated and 'formed' saddle 'T' junctions and no objection is seen to the use of these fittings provided they are of an approved type.

Since there appears to be no specific standard which can be applied to the construction of these 'T' pieces it has been the Society's practice to require prototype units to be submitted to a burst test of 5 × W.P. as per ASME VIII U.G.101. Also, in the case of all units the welding to be subjected to 100% X-ray test as per U.W.51. It will be appreciated the test is required to prove the suitability of the whole 'T' piece. The following slides show the results of some tests carried out on the type of saddle pieces referred.

It is noted that reference is made to a test pressure of 1.3 × WP for Cu. Ni. alloy piping. Whilst this may be considered on the basis of certification in accordance with national authority requirements it would appear to contravene the Society's requirements for hydraulic testing of piping systems which requires the systems to be tested to 1.5 × W.P.

Page 20 Classification Requirements

Para. 4.1 1st Paragraph

This statement is not strictly correct since the mobile unit may consist of a drilling and production unit e.g. Conoco Hutton T.L.P.

The I.M.O. MODU Code (A414 Xl) is, as stated, for mobile offshore drilling units and may not necessarily be applicable to fixed drilling units, albeit it is understood the requirements in relation to hazardous areas are applied to both fixed and mobile drilling units.

Page 21 N.M.D. requirements

It may be pertinent to draw attention to a recent N.M.D. instruction in relation to column/pontoon supported (semi submersible) drill/production platforms in that the emergency source of power is to be capable of operating under adverse conditions of trim—35° in any direction. Since the fire fighting system must be capable of operation under emergency conditions the above requirements will also be applicable in respect to diesel power units used in conjunction with the fire system.

From Mr. J. R. G. Smith:

This paper is timely in so far as it meets a need, namely, that of providing information to our outside colleagues which will enable them to carry out their duties more easily and therefore, more efficiently. It is a valuable contribution to the Technical Association and I would like to thank the authors for their time and effort.

I would like to ask one short question.

In fighting a fire a considerable amount of water could be put onto and into an offshore installation, and this could in itself cause problems. Are provisions made in the Rules for the drainage of such water?

From Mr. S. Blakeman:

I congratulate the Authors on the production of a paper which no doubt will throw a little light on a subject which must be rather alien to those who have little to do with offshore installations, as well as clarifying some points of the Regulations to those involved.

In the introduction it is stated that requirements are more comprehensive than is generally accepted on ships and that the use of combustible materials is restricted.

My comments in the main will be confined to structural fire protection standards, and testing.

It may not be appreciated that the present D.En. Regulations and Guidance Notes have only been formulated within the last eight years and considering the lack of information and guidance in the earlier days the ground covered has been considerable.

The outcome of being involved in this development has shown, in my opinion, that an offshore installation is indeed a rather different animal to a ship. The approach when forming regulations was similar to that used for ships with a marine application and, as such, reflected in the contents of those regulations. It will be seen that they tend to confine the safety aspects mainly to the protection of personnel and quite correctly too.

However, in practice, the oil companies leave me in no doubt that they consider the protection of their investment, which includes such things as the process and production facilities, just as important.

The protection of plant etc. is generally to a standard which is in excess of that laid down, it is noted, for accommodation spaces, control stations and the like and refers to the hydrocarbon fire approach rather than the Standard Fire Test approach defined by SOLAS and BS 476: Part 8.

In addition the tendency is also to protect the supporting structures of the modules containing the plant, which aspect is not a statutory requirement by the present regulations.

In view of the current practice of using the hydrocarbon fire approach I would like to ask the authors' views on possible future regulations based on these lines.

On the subject of the recorded hydrocarbon fire test curve it is noted that the N.P.D. curve is recorded in figure 2. The parameters of this particular test curve are recorded in the Regulations for Production and Auxiliary Systems on Production Installations of the Norwegian Petroleum Directorate, and incidentally this test is stated therein to be not a 'standardized' test. Nevertheless the requirements of the N.P.D. refer to such a standard and show that on production platforms in the Norwegian sector the standard of structural fire protection is more onerus than that stated in 4.2 'Norwegian Maritime Directorate Requirements for Drilling Vessels and Drilling Platforms'.

On the subject of materials used in the construction of fire walls and modules there has been, by necessity, a development of systems and interface of ideas which have brought together the use of materials in a marine environment by land based architects who previously had little experience in this field. This has resulted in the development offshore of systems not normally used in ship practice, involving sometimes those used in aircraft industries, building construction and land based petrochemical plants.

My own view is that the development of materials and ideas over the last 8 years has been fascinating.

One of the major factors has been the quest for reduction of weight, resulting in lightweight modules, steel being reduced to a minimum and the use of insulation materials not normally used in ship construction.

To mention only a few we have seen the development of flexible seals, based on aircraft practice in one case, and the use of foam insulation in penetrations, though recognized as being combustible in the strict sense of the law, have a role to play in conjunction with other materials.

In the search also to reduce weight the use of itumescent compounds are being used, albeit in restricted areas, the bonus for this material being also that of minimum maintenance, so it is claimed. The use of this material is particularly apt for the insulation of structural members.

Who knows what effect these developments may have in the future shipbuilding design of accommodation for instance. We already have in existence barges known as 'COASTELS' which accommodate up to 900 people, the accommodation being of a lightweight module construction.

Finally on the Fire Test for Flexible Hoses in 2.6 of the paper paragraph 2(v) states 'the test piece is to be internally pressurized with water to working pressure before the start of the test. This pressure is to be maintained during the test without further addition of water'.

I would like to know how the pressure can be maintained without the addition of water during the test if, as could happen, the flexible hose expands in the earlier stages of the fire test.

I trust the above comments will be of some assistance and contribute to the usefulness of the paper.

WRITTEN DISCUSSION

From Mr. J. S. C. Bloomfield:

On page 7 the authors refer to primary deck coverings which will not readily ignite.

On a number of vessels deck coverings in enclosed spaces have been responsible for filling accommodation spaces with thick poisonous smoke when heated by fires with the result that crew have had to evacuate the area reducing their capacity to fight the fire. How are these coverings type tested for fire hazard and what standard is used?

In item 2.4.1 (iv) concerning shutters, manufacturers must present many different designs none of which can be completely air-tight when closed. How does the Society or national authority test and classify them remembering that they may be fitted in differently classed bulkheads?

Referring to page 17 where Halon is automatically released into enclosed spaces it is concluded only one sensor is required to operate to allow release. To eliminate release by accident from an erroneous signal or damaged sensor there is an argument for two sensors to be activated before release of Halon. The author's views would be interesting.

From Mr. J. H. C. Robertson:

The authors deserve congratulations for producing such an informative and practical paper. Its contents should help to dispel any remaining doubts that fire protection engineering is a minor subject.

It is stated in the paper that the U.K. national requirements for installations intended for operation in the U.K. sector of the North Sea are more onerous than the Society's draft rules for mobile offshore units which incorporate the IMO MODU Code and the relevant IACS Unified Requirements. I believe this is the result of a basic difference of approach to the subject between the U.K. Department of Energy and IMO.

In drafting its requirements for fire safety measures the Department of Energy gives the impression of having worked from first principles to ensure adequate protection is achieved; IMO on the other hand appears to have utilised existing requirements for ships, adapting them to suit the needs of mobile offshore drilling units. Whilst admittedly the Department of Energy requirements are intended to apply to a wide variety of types of offshore installations and not just mobile offshore drilling units the difference in the requirements for the latter are significant.

This is most striking in the provision of sea water for fire fighting purposes. The IMO MODU Code states that the total capacity of the fire pumps need exceed 180 m^3/h and if only 2 fire pumps are provided this could be reduced to 90 m^3/h if either pump is out of action. The Department of Energy requirements on the other hand require the fire pumps to be capable of providing 100% of the water demand with any one fire pump out of action. The water demand is related to a realistic assessment of the quantity of water required to combat any fire other than that resulting from a 'blow out' and may amount to several hundred if not thousand m^3/h.

It is remarkable that such a situation should exist and presumably contributes to the confusion and complexity referred to by the authors in Section 7 of the paper. Their further views on this matter would be of interest.

The Norwegian Petroleum Directorate has requirements for hydrocarbon fire tests and many oil companies have their own requirements for such tests, the latter generally based on the Mobil time/temperature curve. It is understood that the U.K. Department of Energy is developing requirements for a hydrocarbon fire test. As hydrocarbon fires develop faster and burn hotter than cellulosic fires, requirements for certain fire resisting divisions to be able to withstand hydrocarbon fires would appear to offer increased safety. Can the authors state if introduction of a hydrocarbon fire test is likely in the Society's Rules or in IMO and IACS?

AUTHOR'S REPLY

To Mr. Rennie:

To the best of our knowledge the risk of fire and explosion on board offshore installations has not been quantified. As in most other industries, including the shipping industry, construction and operation of the installations have preceded safety legislation and both national and international regulations have only been developed at a late stage.

Both nationally and internationally the fundamental decision taken was that the basis should be the marine standard rather than oil refinery practice, although the construction and operations were directed by companies with an oil refinery background.

Of course the rules were written in response to the development of the offshore oil industry in the North Sea and the initial expertise was imported from USA where oil had been extracted offshore for some considerable time.

In the initial meetings of the IMO working group set up to develop the regulations the UK and Norwegian delegations

wanted to base them on the fire safety regulations for oil tankers. However the USA delegation protested that the hazards were dissimilar since there was no great quantity of oil on drilling or production platforms, indeed they contended that there was no great fire hazard at all! Perhaps their failure to recognise such a hazard is the reason why so many disastrous fires have occurred on their side of the Atlantic.

It would be nice to be able to say that the measures in force were arrived by analysis of the hazard, but the fact is that they were derived largely by a committee applying criteria which had proved successful in ships. That is not to say that the regulations are inadequate or that the method of development was unusual. Their adequacy is evidenced by the good safety record of the industry and the method of development was that used in other similar cases.

To Mr. Crawford:

At the time of writing, the remote control safety equipment indicated in Section 3.4 was the only mandatory requirement established by D.En. for installations in U.K. waters which related to safety systems other than those for drilling and gas/oil processing where Mr. Crawford's comments would apply. The Society's Engineering Departments have subsequently been actively involved with D.En. in the preparation of 'guidance notes' concerning emergency shut-down (E.S.D.) systems and Mr. Crawford's contribution concerning additional equipment to that listed on pages 10 and 11 gives a brief insight to the engineering principles involved. As indicated in the paper, Section 3 relates to fixed installations outside U.K. waters and the deluge systems indicated on page 14 would be required for certification of the installations. The Society does not have Classification Rules, as such, for fixed installations.

The fire test for flexible hoses has been submitted to D.En. for endorsement as the U.K. standard. Discussion with D.En. and the other C.A.'s. is still continuing and the requirements set out in the paper must remain, for the present, as a proposed test. The use of water as a pressurising medium was chosen in view of the very high working pressures involved (up to 300 bar) where an ignited failure could put both lives and property at risk. The fire test for valves given as a reference is not valid for flexible hoses, either with respect to test pressures or consequences of failure, where an oil leak past the valve seat would not have the same catastrophic results.

The fire protection measures required for fire pump units, where these are located adjacent to each other, would be an A-60 Class firewall separating the pump units together with firewalls of A-0 or A-60 Class on the other sides depending on the nature of the equipment in the immediate vicinity. An open louvred wall could even be acceptable for one wall if this was the seaward boundary of the platform and did not infringe on a classified hazardous area. The means of access to any fire pump room where these are closely grouped would normally be considered in the same way as the requirements for escape routes i.e. two means of entry/egress and as widely separated as possible.

Mr. Crawford is quite correct that the test pressure of $1.3 \times$ W.P. stated in the paper relates only to the requirements of the U.K. for copper nickel alloy piping. The Society's standard is $1.5 \times$ W.P. together with the other tests and inspections given in the contribution.

As far as fire aspects are concerned the unique type of floating drilling/production installation such as the Hutton tension leg platform (T.L.P.) would not be examined as a mobile offshore installation but as a fixed installation, which is the state of its normal operational mode. Thus the MODU Code requirements would not be applicable.

To Messrs Blakeman, Robertson and Smith:

Mr. Smith and Mr. Robertson raise related questions concerning the capacity for pumping water for fire fighting purposes and the arrangements to be provided for dealing with excess quantities.

The differences between the regulations established by the U.K. Dept. of Energy and IMO concerning the minimum number and capacity of the required fire pumps for mobile installations has been clearly highlighted by Mr. Robertson and in the authors' opinion the method adopted by the U.K. Authority in assessing the maximum water demand, caused by a single fire anywhere on the installation, to be the correct approach. Whilst it may be argued that to install fire fighting pumps of greater capacity than the bilge pumps could give rise to the possibility of flooding and consequent loss of stability, it should also be kept in mind that the additional water demand for mobile installations will be to supply deluge systems for the protection of the well-head/drilling tower area and the well-test equipment, all of which will usually be located on the open deck.

Thus the capacity of the bilge pumps is not a relevant criterion for establishing maximum fire pump capacities since the excess unevaporated water will be shed over the installation's side with only a small amount of water 'standing' on deck at any particular time. This principle has already been applied by the Society in the Rules for firefighting units with the class notation 'with water spray'. As stated in the paper, all the external surfaces of such units that would be exposed to the effects of a fire are to have a cooling water spray applied and the excess unevaporated water is expected to run off the deck. For the unit illustrated in the paper the deck water spray system is capable of delivering about 3,400 m^3 per hour and approximately $\frac{2}{3}$ of this would be evaporated when fighting a large fire at close quarters. A possible difficulty for such units, however, could be the use of the water spray system as a precaution prior to the event of fire, such as when approaching an installation with an unignited blow-out. Without any evaporation the application of such a quantity of water could cause a significant amount of water to be retained on deck at any one time thus having an effect on the unit's stability.

In the case of the fixed installation, supported on legs from the sea-bed, the question of stability of course does not arise and the excess water will be taken by the drains system or shed over the installation's side.

Mr. Blakeman and Mr. Robertson both asked about the introduction of requirements to carry out fire tests using a time/temperature relationship representative of a hydrocarbon fire. As indicated in figure 2 of the paper the Norwegian Administration and Mobil have already published their interpretations of such a fire. It is understood that the U.K. D.En. is presently conducting an investigation to establish a test procedure for a hydrocarbon fire which will be used in due course in amendments to the Guidance on Design and Construction. It is likely that the D.En. will adopt the Mobil Curve. Whilst there is no known intent of IMO or IACS to introduce structural fire protection requirements based on a hydrocarbon fire, it could be expected that if the U.K. D.En. establishes such requirements for mobile offshore installations, which would be applicable to all installations working in U.K. territorial waters regardless of flag, then the influence of both the Norwegian and U.K. Administrations may prove to be a significant factor in the introduction of such requirements internationally at some future date.

Mr. Blakemans' request for information on possible future legislation concerning structural fire protection against the effects of hydrocarbon fires is possibly best answered by identifying the existing problem areas at present not covered by any legislation. Statistically 30% of all blow outs ignite and the ignited blow out is the catastophic situation not presently addressed by the U.K. Regulations which are preventative in overall scope rather than curative. Burning oil falling onto the surface of the sea from a blow out could within 20-30 minutes raise the temperature of a supporting steel jacket structure to a point where it could no longer carry the topsides load. A similar

fire acting on a concrete gravity structure may take several hours before spalling of the concrete exposes the steel reinforcement and ensuing failure. Thus consideration of the protection that could be given to the primary structure in order to give sufficient time for safe evacuation would appear to be a significant area for future legislation, together with possible amendment of the existing requirements in light of the operating experience gained since the introduction of the present legislation and new developments in the industry.

With regard to Mr. Blakemans' question concerning the test rig for flexible hose fire testing, the statement 'without further addition of water' was included to prevent a very large pump being used to maintain pressure after a burst. The usual arrangement is for a small high pressure pump to be installed with a pressure relief/regulator to a by-pass line and header tank thus maintaining the required pressure at all times during test without the bulk addition of water.

To Mr. Bloomfield:

Assessment of the fire properties of primary deck coverings should be made in accordance with IMO Resolution A 214 (VII) 'Improved Provisional Guidelines on Test Procedures for Primary Deck Covering'. Samples of the deck covering are applied to a 5mm thick mild steel plate measuring about 600mm square and exposed to a furnace where the time/temperature relationship follows the first 30 minutes of the standard fire test (the curve marked BS476 in Fig. 2) the steel side being exposed to the fire. Three specimens are used, two of which are for the test of ignitability, test duration 15 minutes each, and the third for smoke and toxic products during the full 30 minutes of testing. The deck covering can be classified as 'not readily ignitable' if neither of the ignitability specimens exhibits any flaming when a test flame is applied to the surface being tested. The test flame should be applied at one minute intervals throughout the testing. The quantity of smoke and toxic products given off are to be recorded but no criteria have been established for acceptable limits, this being left to the satisfaction of the Administration having jurisdiction.

Fire dampers for use at penetrations of A Class divisions should be tested in the closed position to the same parameters as an A Class division, i.e. the one hour standard fire test, during which time there should be no loss of stability nor passage of smoke or flames. Where insulation is also required on the A Class division then this should also be applied to the fire damper casing and ventilation trunking to ensure that no heat bridges occur in way of the penetration of the division concerned.

With regard to the automatic release of Halon systems it is agreed that this could be on the initiation of only one fire detector. In practice sophisticated control systems are employed to eliminate the problem of spurious release such as by voting systems where two out of three detectors must be activated to initiate a signal for release. Other control mechanisms are used for particular types of fire detector, such as for the U.V. detector which, when located in an open situation at a well-head, may be triggered by the flicker response of sunlight reflected from the surface of the sea. In this case two detectors could be used, one aimed at the surface of the sea, the other at the platform fire hazard. Any signal received at the fire hazard detector would be compared with the signal received at the reference detector and, where these are the same, there would be no fire detection response at the control station. In general, however, fire detection systems on offshore installations which generate automatic operation of equipment are usually comprised of more than one detector type, or a number of detectors of the same type, and a control system suitable for the detector arrangement such that the possibility of spurious release is reduced to an absolute minimum. Whilst such sophistication may appear expensive the cost is in fact small compared with the possible loss of production if the detection system triggers any part of the E.S.D. system.

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SOME MARINE MACHINERY FAILURES AND THEIR CAUSES

R. F. Munro

Paper No. 3. Session 1982–83

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

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SOME MARINE MACHINERY FAILURES AND THEIR CAUSES

by R. F. MUNRO

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1. INTRODUCTION

This paper consists of a collection of cases assembled from reports reaching Headquarters, from which lessons are to be learned.

In 1975 the Society drew attention to the unacceptable incidence of machinery space fires and took the positive step of reprinting the Department of Trade Merchant Shipping Notice No. M 707 in Circular No. 2320. At the time of writing, the incidence of engine room fires continues to cause concern and for this reason a number of Merchant Shipping Notices are reproduced in the Appendix for ready reference, and further Notices, which are currently in circulation, are listed in the References (Section 10).

For many years the effects of stress concentrations have been recognised by engineers and yet very serious damages are still being experienced today by failure to provide adequate radii where they are most needed (Sections 2.1.2, 4.9, 4.10).

Reports continue to show that many serious engine breakdowns occur soon after periods of overhaul.

While Surveyors are not normally concerned with the dismantling and reassembly of machinery, they do become deeply involved when things go wrong and it will certainly not be out of place for them to draw attention to the very detailed instructions supplied by the designers (Section 4.3).

In all of their inspections connected with the machinery of ships the Surveyors should have as their objective the ensuring of conditions vital for the safety of the ships and their passengers and/or crews.

The Surveyors are aware of the various methods employed by the Society to pass to them information extracted from the numerous reports received in Headquarters and they are in a unique position to perform a valuable service to the shipping industry by discussing these matters (while maintaining strict confidentiality) in drawing offices, workshops, engine rooms etc.

By this means it is hoped that it may be possible to help people at all levels in the industry to learn from the mistakes of others, resulting in highly desirable reductions in loss of life and damage to property.

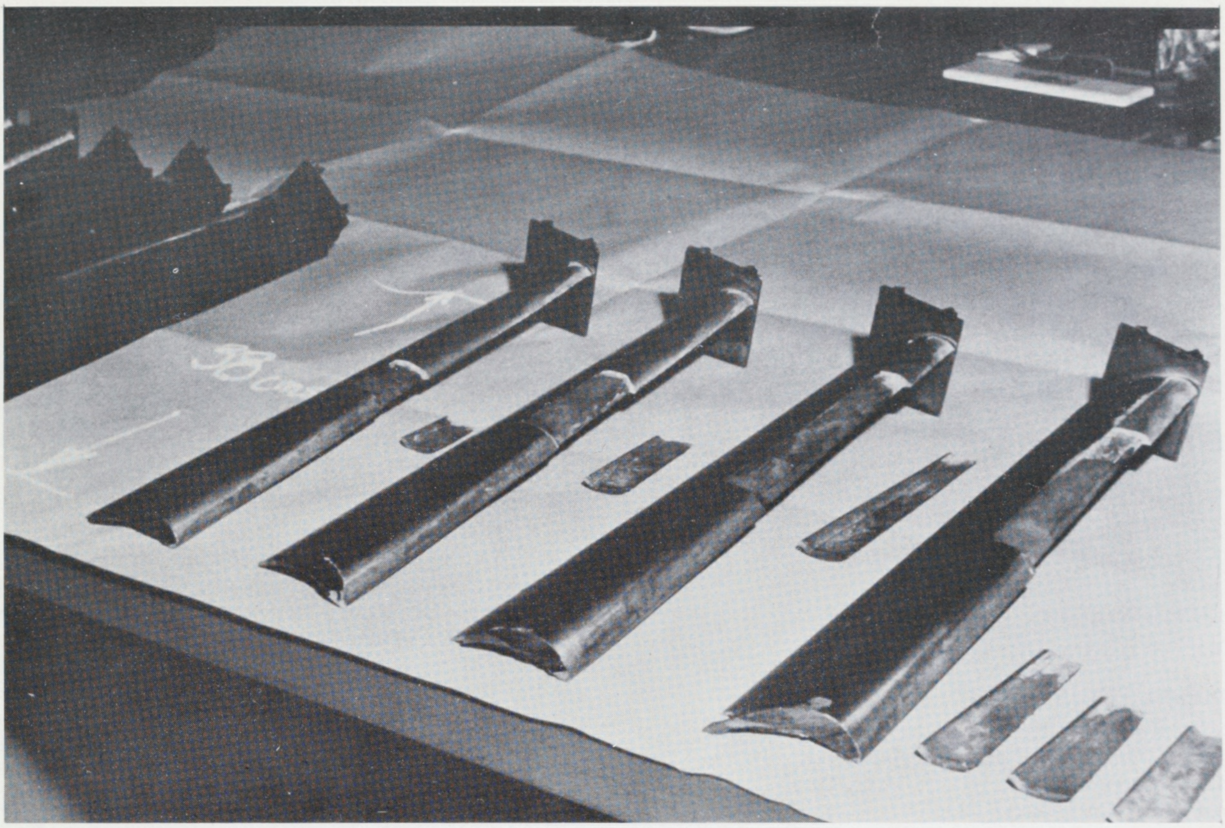


Fig. 1

2. STEAM TURBINES

2.1 Blading, Stellite Detached

21,000 kW two-casing turbine.

Figure 1 shows low-pressure turbine blades from which the stellite protection has become detached.

One case was a consequence of severe overspeeding. In the further three cases which are known to the builders, the cause was considered to be overheating during prolonged running astern resulting in the inner (radially) ends of the stellite pieces becoming loose, separation taking place in the interface between the brazing filler metal and the blades due to thermal expansion differences of the two materials.

In normal manoeuvring the temperature at the exit end of the L.P. turbine does not reach a level at which this damage can be suffered, but cases can arise where a master may require the highest possible power astern over a long period and high temperatures can be reached.

In this particular case, examination of the records shows that the ship suffered very severe damage to the bottom plating and internals due to grounding some years before the blade damage was revealed, and it is most likely that strenuous efforts would have been made to refloat the ship. These matters should be borne in mind when carrying out turbine surveys.

2.2 **Blading, Missing Shrouding**

19,769 kW two-casing turbine.

On two occasions within three months the Chief Engineer examined the L.P. rotor of this turbine because of vibration and found shrouding missing from the last stage blading (see Fig. 2).

In course of a thorough investigation, it was found that the holes in the shrouding to accommodate the blade tenons had sharp edges on the underside, causing stress concentrating notches in the tenon roots during the peening/riveting process (see Fig. 3).

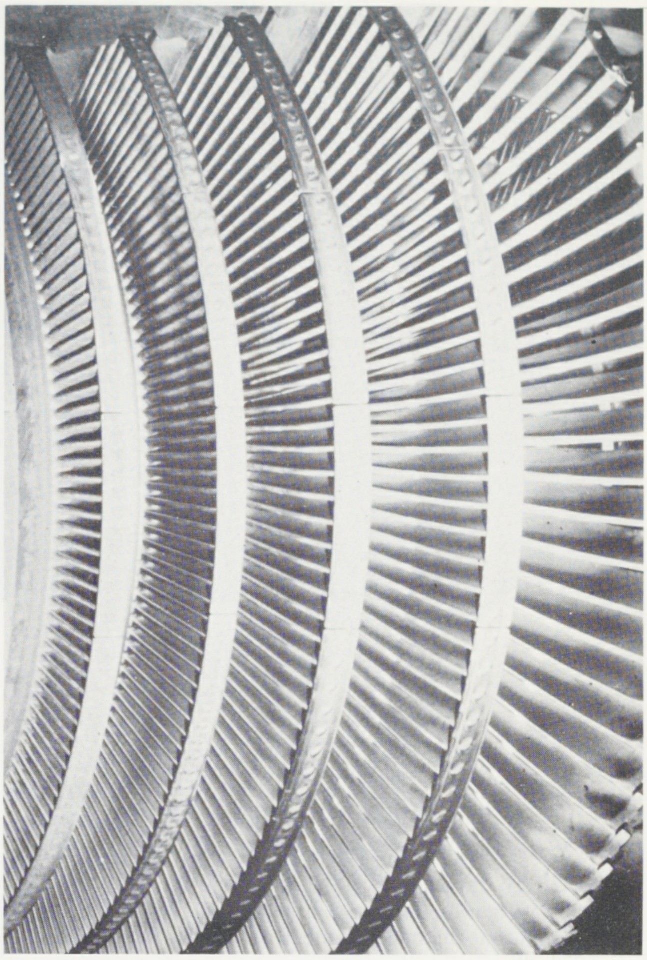


Fig. 2

Fig. 3

Fig. 4

3. CONDENSERS

3.1 Water Box Damage

23,380 kW turbine driven container ship.

On investigating the source of unusually high bilge water, it was found that the main condenser water box was perforated (see Fig. 4).

The damage was due to repeated impact of the steel sacrificial anode carrier which had become detached from the inspection door and carried round violently in the great turbulence in the cast iron water box (see Fig. 5).

The connection to the inspection door should be carefully examined.

Fig. 5

4. DIESEL ENGINES

4.1 Crankcase Explosion

Eight cylinder, 740 mm bore—5,215 kW.

This ship suffered two crankcase explosions. The first happened at 0300 hours and caused minor damage. After waiting for the engine to cool down, the running gear was examined and because nothing unusual was found the engine was restarted and the passage resumed.

Shortly afterwards there was a violent explosion which resulted in a serious fire and the death of four crew members. Figure 6 shows the condition of the integral thrust collar which had been overlooked by the engineers and Fig.7 the state of the ahead thrust pads from which the white metal had been completely melted out.

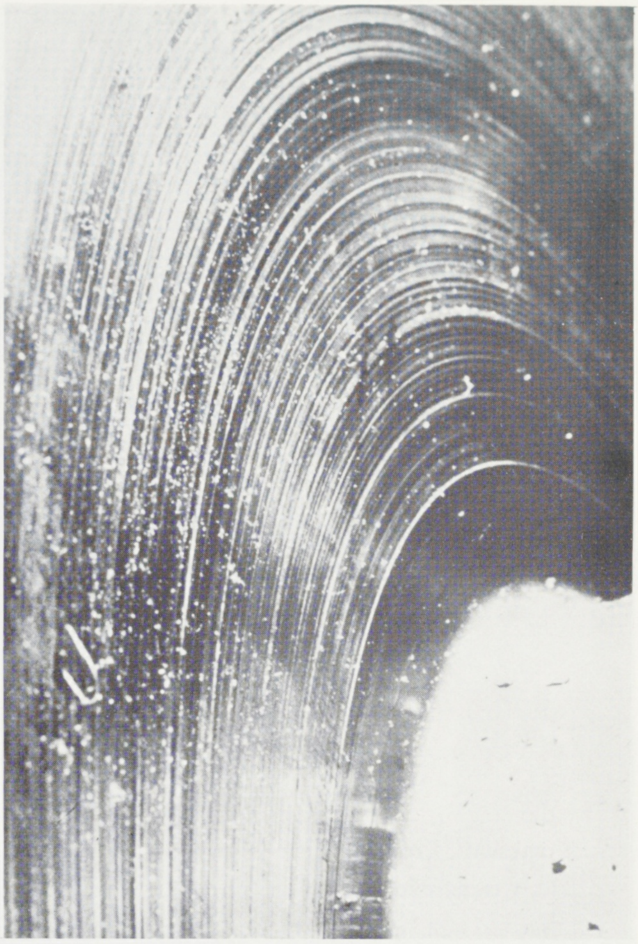


Fig. 6

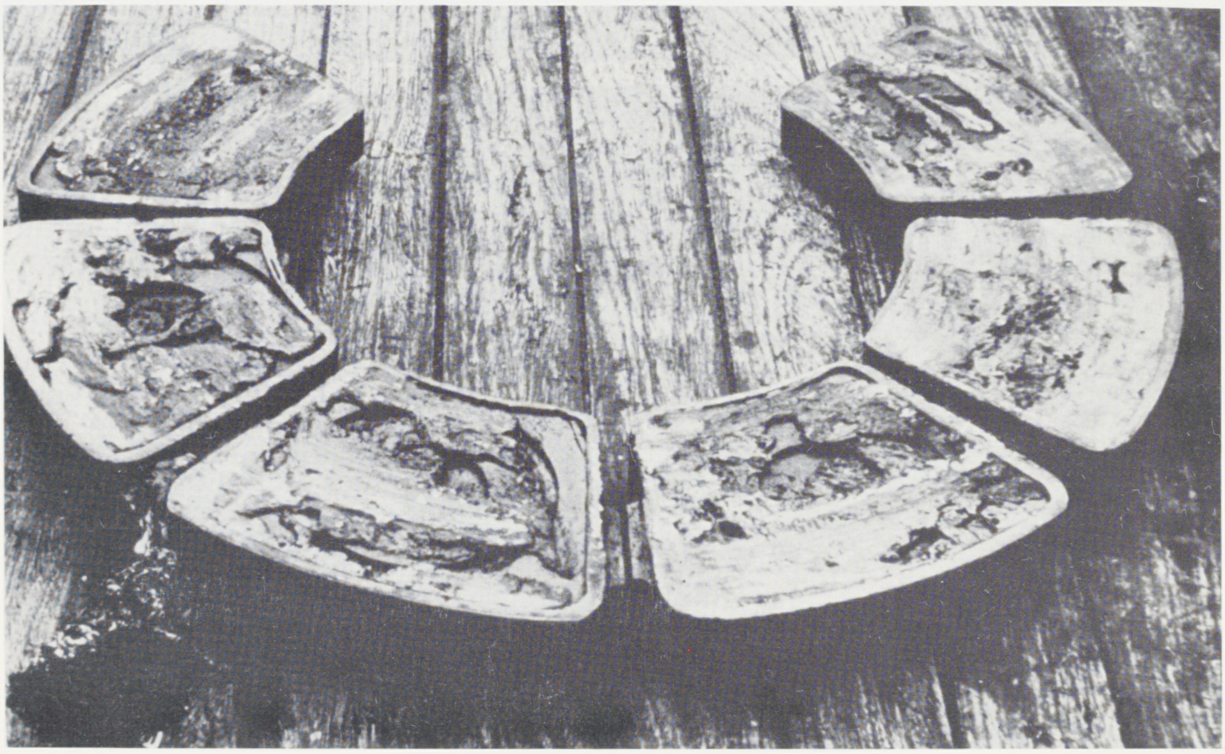


Fig. 7

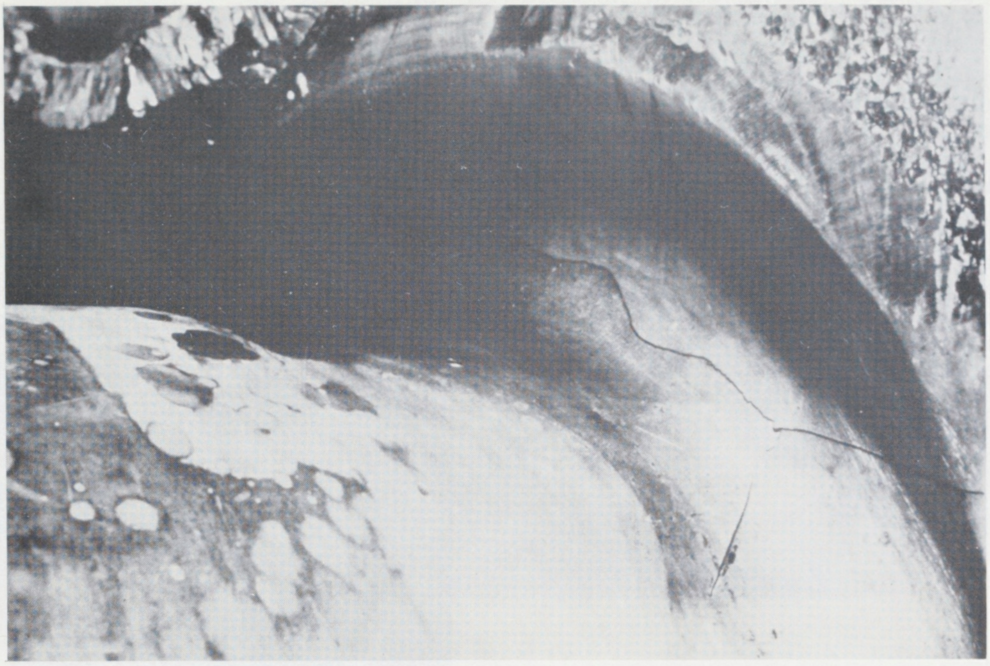


FIG. 8

4.2 **Crankshaft, Cracked Repair Weld**

2,328 kW cargo ship.

This ship was built in 1959. On a routine inspection after two years in service a severe crack was found in the undercut fillet between crackpin and web (see Fig. 8).

Investigation revealed that a local repair by welding had been carried out during manufacture in the steel foundry. Figure 9 clearly shows the heat affected zone after etching.

For many years the Rules have been explicit on the subject of permitted and prohibited zones for repair welding on castings for crankshafts, because of the cyclic stresses involved.

FIG. 9

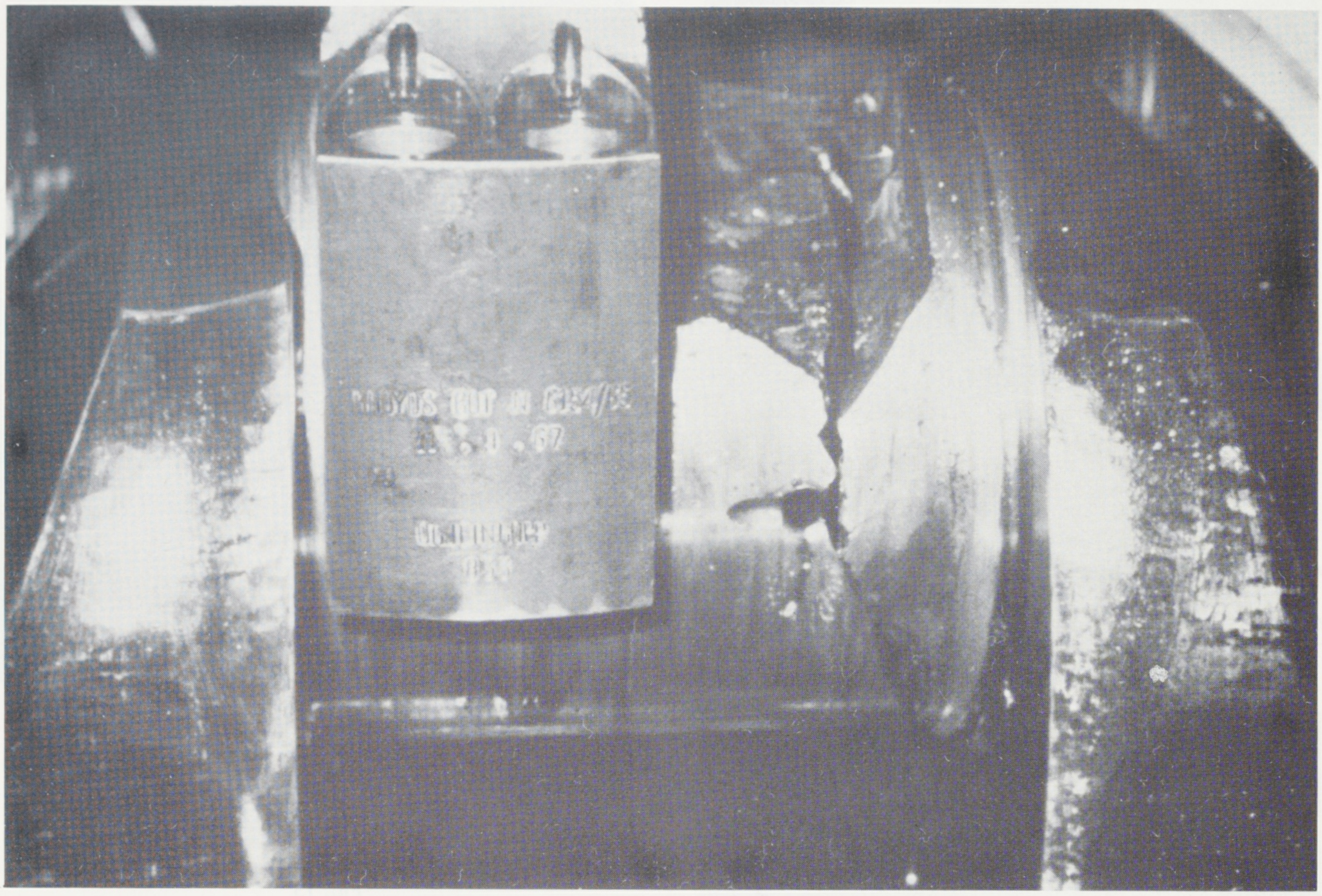


Fig. 10

4.3 **Fatigue Failure**

3,760 kW Vee engine.

This medium speed engine has thin wall bearing shells on the crankshaft. There have been many cases of damage of this type following bearing failure (see Fig. 10).

With these bearings it is essential that they are a good fit in their housings with the locking horns in their correct positions. The clamping of the upper housing should be effective and the bolts tightened to the designers' recommended torques.

Scrupulous cleanliness should be maintained at all times.

4.4 **Various Cracks**

4,476 kW medium speed engine—bulk carrier.

Figure 11 shows the crankpin in which the Chief Engineer had ground a crack he had found near the oil hole.

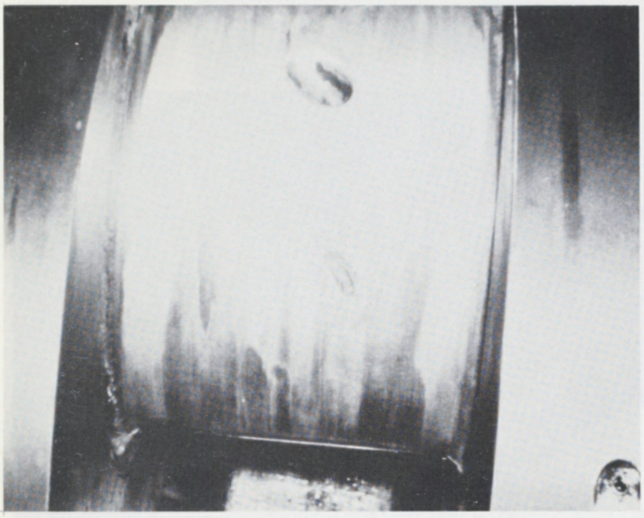


Fig. 11

Figure 12 shows the result of magnetic crack detection on the white painted crankpin.

It will be seen that the 9 mm deep and 40 mm long ground zone has not removed the crack which, as indicated at '1' and '2', extends beyond the gouge.

Fig. 12

Fig. 13

Figure 13 is the result of a careful test of the crankpin by one of the Society's specialist non-destructive examining Surveyors using a permanent magnet.

At '1' can be seen a serious branching crack having torsional connotations, and large areas of crazed and longitudinal cracking which are the result of excessive heat. Figure 13 also shows a useful technique whereby a permanent record of a magnetic powder 'picture' can be made by the careful laying on of transparent adhesive tape and then transferring it to a sheet of white paper. The process can, of course, be repeated as often as required.

Failure to deal with hair-line cracks has caused a number of subsequent crankshaft failures.

Dye penetrant checks have often failed to show these cracks and Surveyors should emphasise the need for magnetic particle testing as described above.

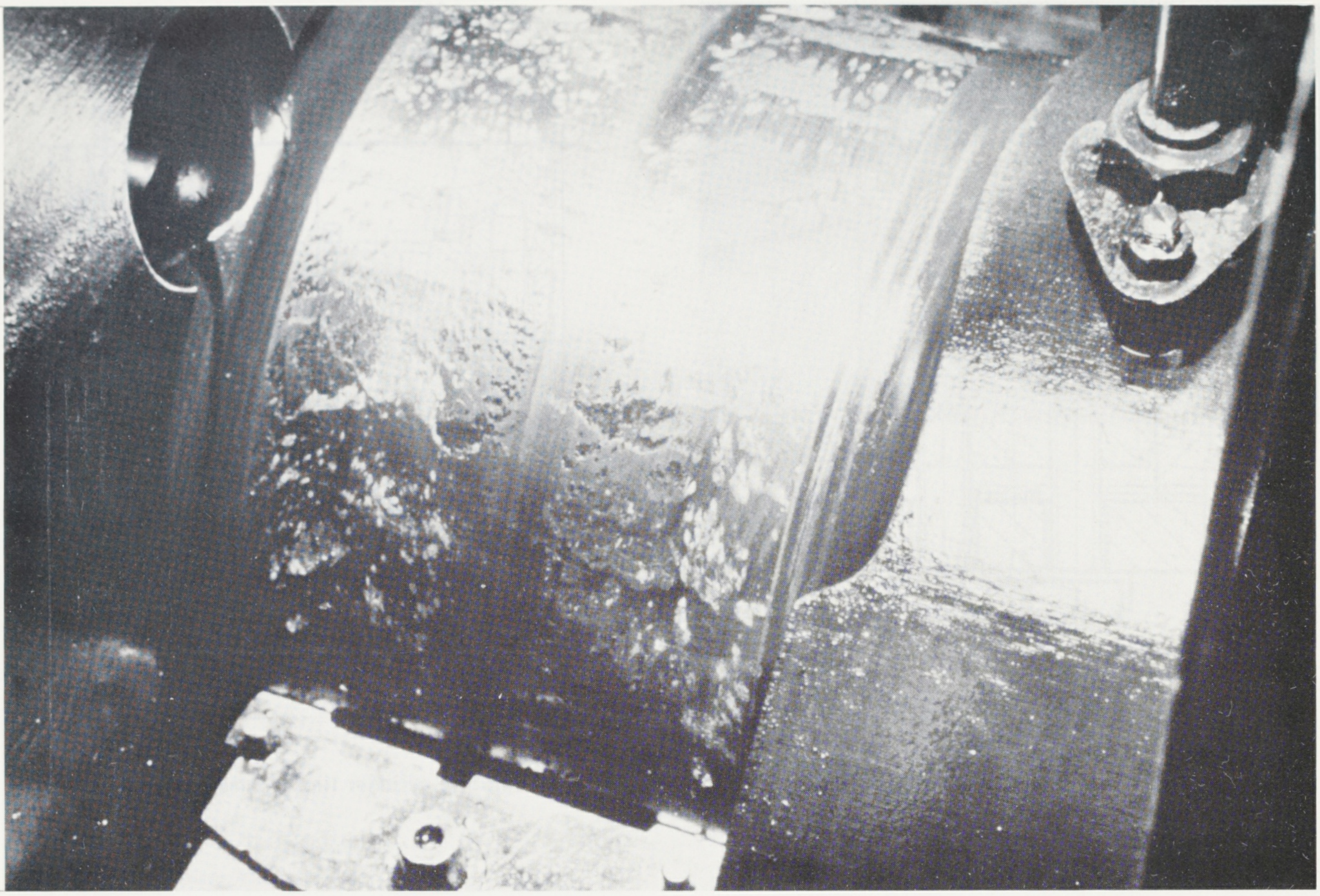


Fig. 14

4.5 Corrosion

Some years ago, when there were many engines at sea which did not have the benefit of a diaphragm dividing the scavenge space from the crankcase, the type of damage shown in Fig. 14 was common, and because these engines had water-cooled pistons it was accepted that the corrosion was due to sulphorous contamination of the lubricant in the presence of water leaking from the cooling system.

Today very similar severe damage is occasionally seen but is due to microbial infection of the lubricating oil. Similar corrosion can result if hydraulic systems and piston coolants become infected.

Portable microbiological laboratories are available for regular use by Chief Engineers and a number of Shipowners have placed them on board their ships.

When infection is detected by this means, the appropriate biocide can be introduced to the system thereby arresting the costly damage which would otherwise result.

For further information refer to References (1) and (2).

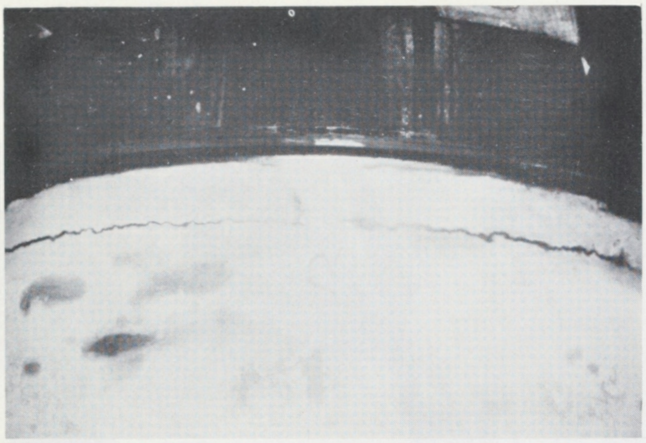


Fig. 15

4.6 Cylinder Liners

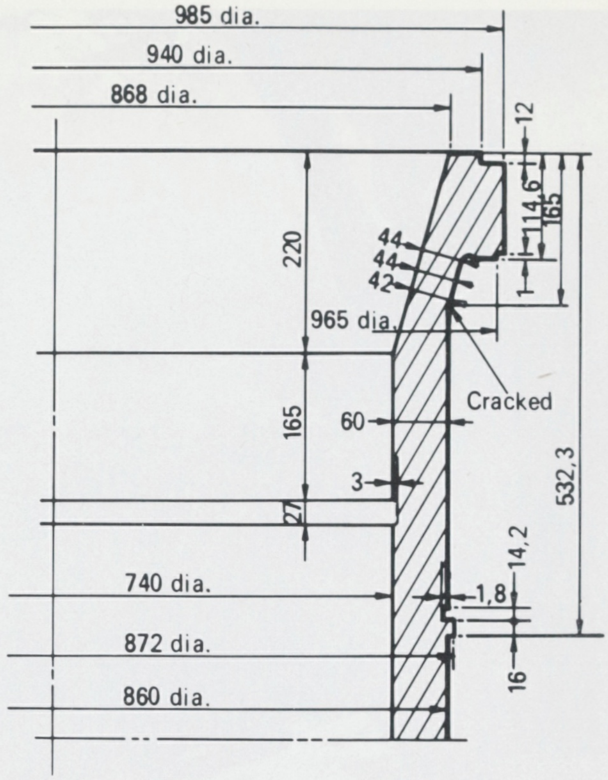
Six cylinders, 740 mm bore—7,908 kW.

When, at a periodical survey, the liner shown in Fig. 15 was found to be severely cracked it was decided to examine the remainder, whereupon they were all found to be cracked at precisely the same position.

Figure 16 is a section through the cracked liners and the dimensions should be compared with those in Fig. 17 which were found in the original spare liner secured to the engine room casing side.

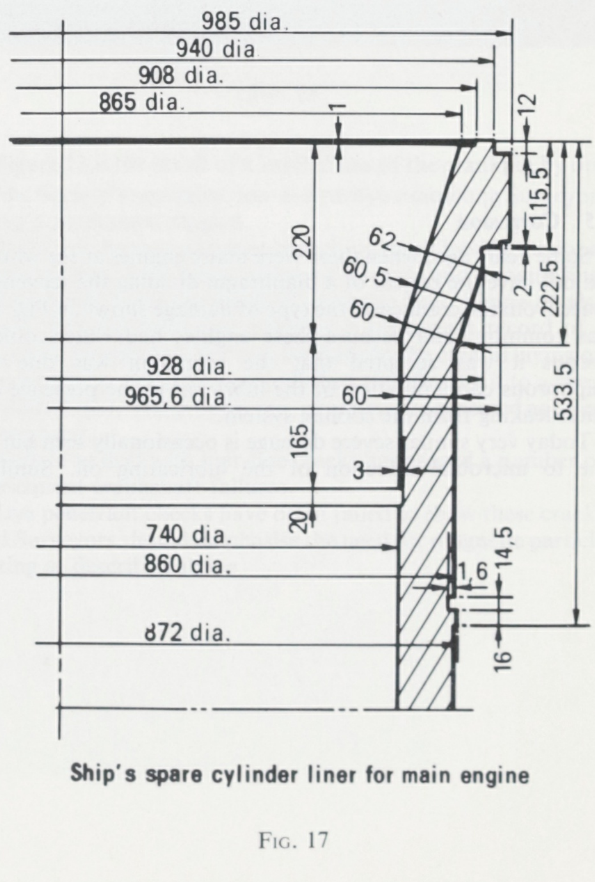
For a number of years the principal engine builders have complained in public about the activities of 'pirate' suppliers, and the dangers of buying components which do not have the benefits of the designers' research, development and experience are clear.

Spare parts may not always be what they appear.



Existing cylinder liner for main engine

Fig. 16



Ship's spare cylinder liner for main engine

Fig. 17

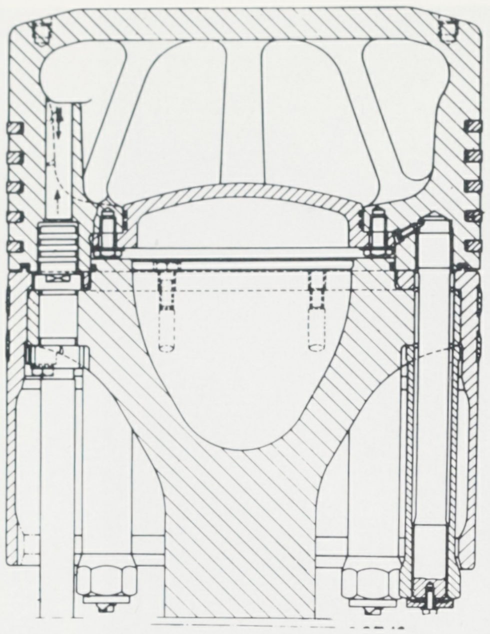
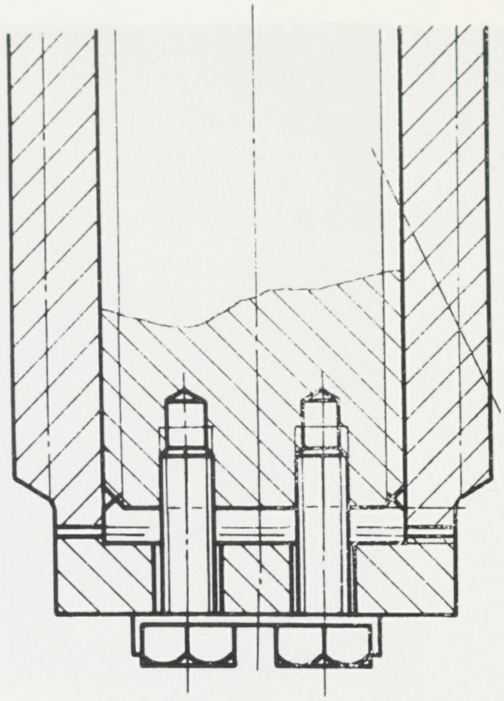



FIG. 18

4.7 **Piston Securing Arrangements**

Six cylinder, 760 mm bore—7,612 kW.

During a normal sea passage a tapping sound was heard in phase with the engine revolutions but the engine was not stopped for investigation.

The sound gradually became louder and eventually the engineer on watch telephoned the Chief Engineer.

Figure 18 shows the assembly of piston rod, skirt and head, and attention is drawn to the securing arrangement for the long tubular nut. To prevent the two set screws from turning, a soft iron tab washer is provided; a tried and trusted device used by mechanical engineers for generations.

It is, however, important to remember that these tab washers should be used once and thrown away, otherwise through fatigue, the tabs are liable to break off with disastrous results, and could have been the cause in this case.

The noise was being caused by the repeated impact of one of the tubular nuts upon the cast iron diaphragm dividing the scavenge space from the crankcase (see Fig. 19).

As the nut continued to turn back the blows eventually smashed the casting. Pieces were struck by the whirling crank throw causing sparks and when the scavenge air blasted into the hot oil-rich crankcase a violent explosion occurred which blew the doors off, not only the engine, but also the engine room.

The Chief Engineer, who was descending the engine room ladders to investigate, died.

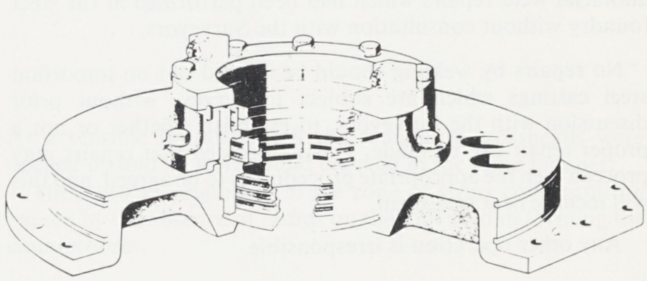


FIG. 19

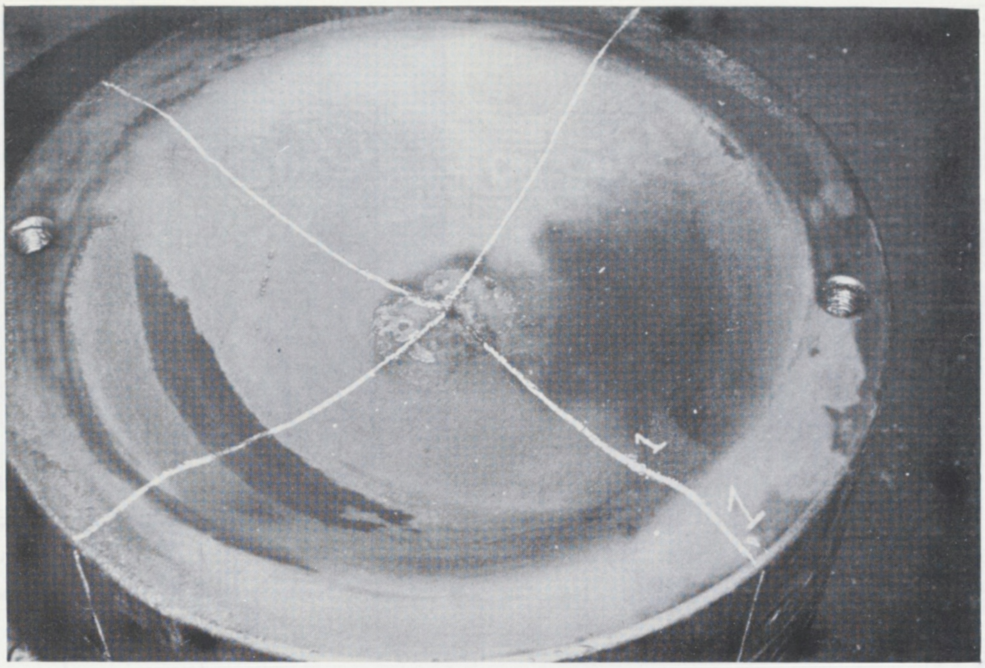


Fig. 20

4.8 Cracked Piston Crown

Seven cylinder, 760 mm bore—6,341 kW.

Figure 20 shows an oil-cooled piston crown which cracked allowing quantities of cooling oil into the combustion space resulting in a violent fatal explosion.

Under investigation the piston was polished and etched and Fig. 21 shows the cracks and the heat affected zone in way of unofficial weld repairs which had been performed at the steel foundry without consultation with the Surveyors.

No repairs by welding should be carried out on important steel castings which are subject to survey, without prior discussion with the Surveyors, to establish whether or not a proper repair can be made. Having decided that repairs may proceed then the appropriate procedure is to be agreed, and this will include heat treatment.

Any other operation is irresponsible.

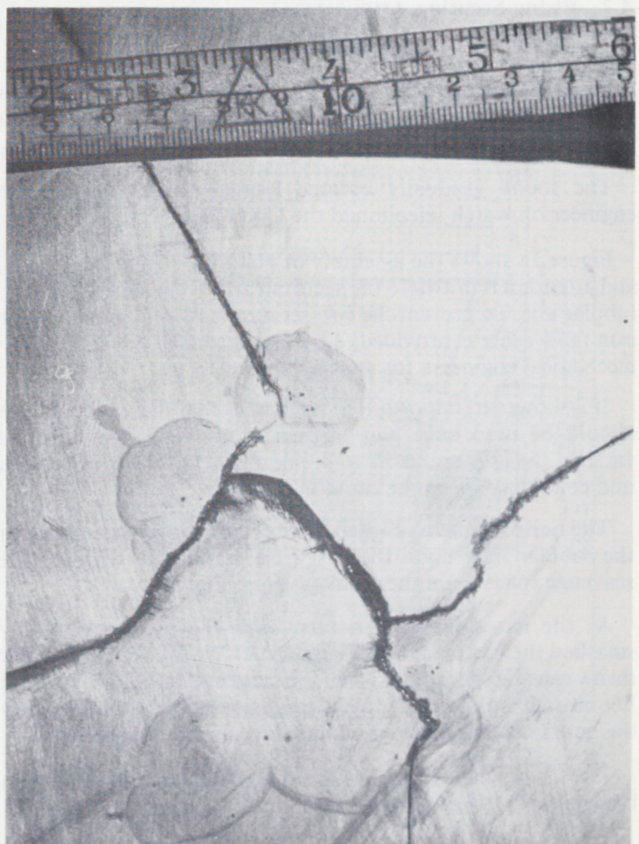


Fig. 21

Fig. 22

4.9 **Crosshead (Stress concentration)**

Six cylinder, 750 mm bore—9,176 kW.

During a routine periodical survey of Nos. 4 and 6 crosshead bearings, the pins were found to be cracked as shown in Fig. 22.

As a sensible precaution all the remaining crossheads were opened up and all were found cracked in the same manner.

These cracks originated in the zone of stress concentration caused by the absence of radius on the tool used in forming the counterbores.

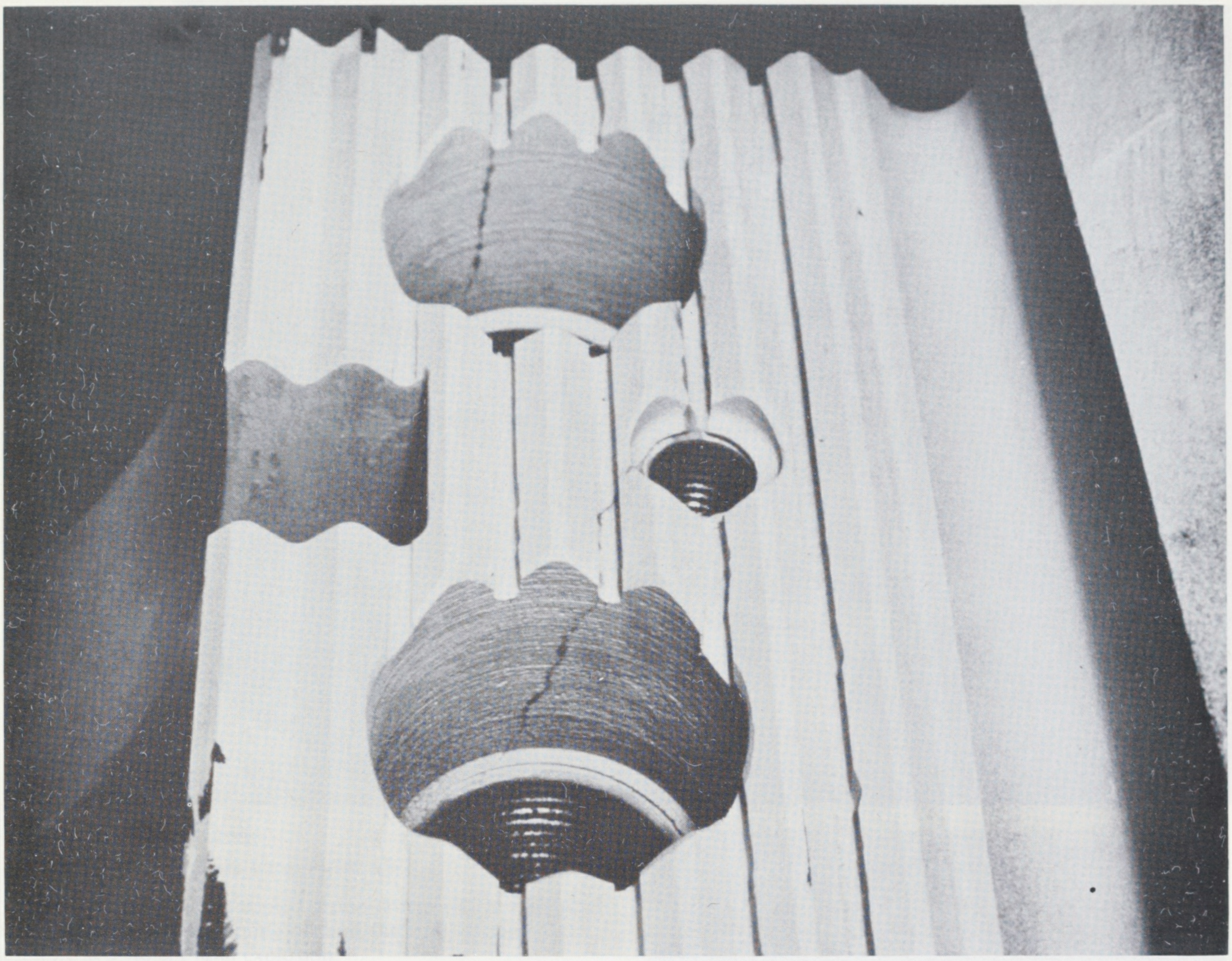


FIG. 23

4.10 **Bedplate (Stress concentration)**

Cast iron, twelve cylinder, 410 mm bore—4,476 kW.

In this medium speed engine type there were many cracks reported in the grey cast iron bedplates which were serrated in way of the main bearing keeps as shown in Fig. 23.

A number of bedplates were replaced in nodular cast iron, which was adopted as the material for all future production after the nature and extent of the problem had been recognised.

A number of the original bedplates have operated for some years without defect, and many were modified to reduce the stresses in the serrations.

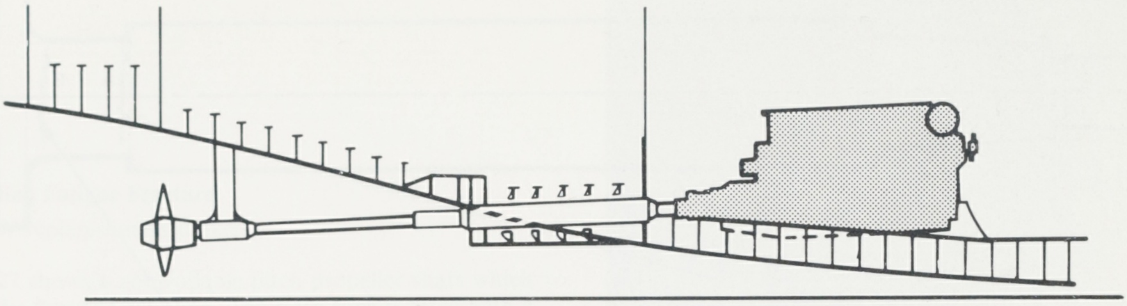


FIG. 24

5. SCREWSHAFTS

5.1 Fracture

Twin-screw diving support ship—each shaft 1,566 kW.

In this ship, the carbon steel screw shafts have stainless steel liners shrunk-on in way of the bearings in the stern tubes and 'A' brackets. The length of the shaft between these sleeves is protected by a glass fibre reinforced coating which is fully exposed when the ship is in dry dock (see Fig. 24).

Almost exactly 12 months after the ship had been in drydock, a propeller was lost due to fracture of the shaft in way of the end of the liner at the 'A' bracket. The fibre glass coating must have been defective, allowing penetration of sea water to the screwshaft with the consequent establishment of an electrolytic cell at the stress concentration due to the sharp edge of the liner.

The resultant stress/corrosion fatigue produced the multi-start fracture shown in Fig. 25.

It is essential that all concerned with the safe and efficient operation of the machinery are completely satisfied with the integrity of these fibre glass coatings at each drydocking, even if this means exposing the shaft to check that corrosion is not actively present; the coating subsequently being made good.

FIG. 25

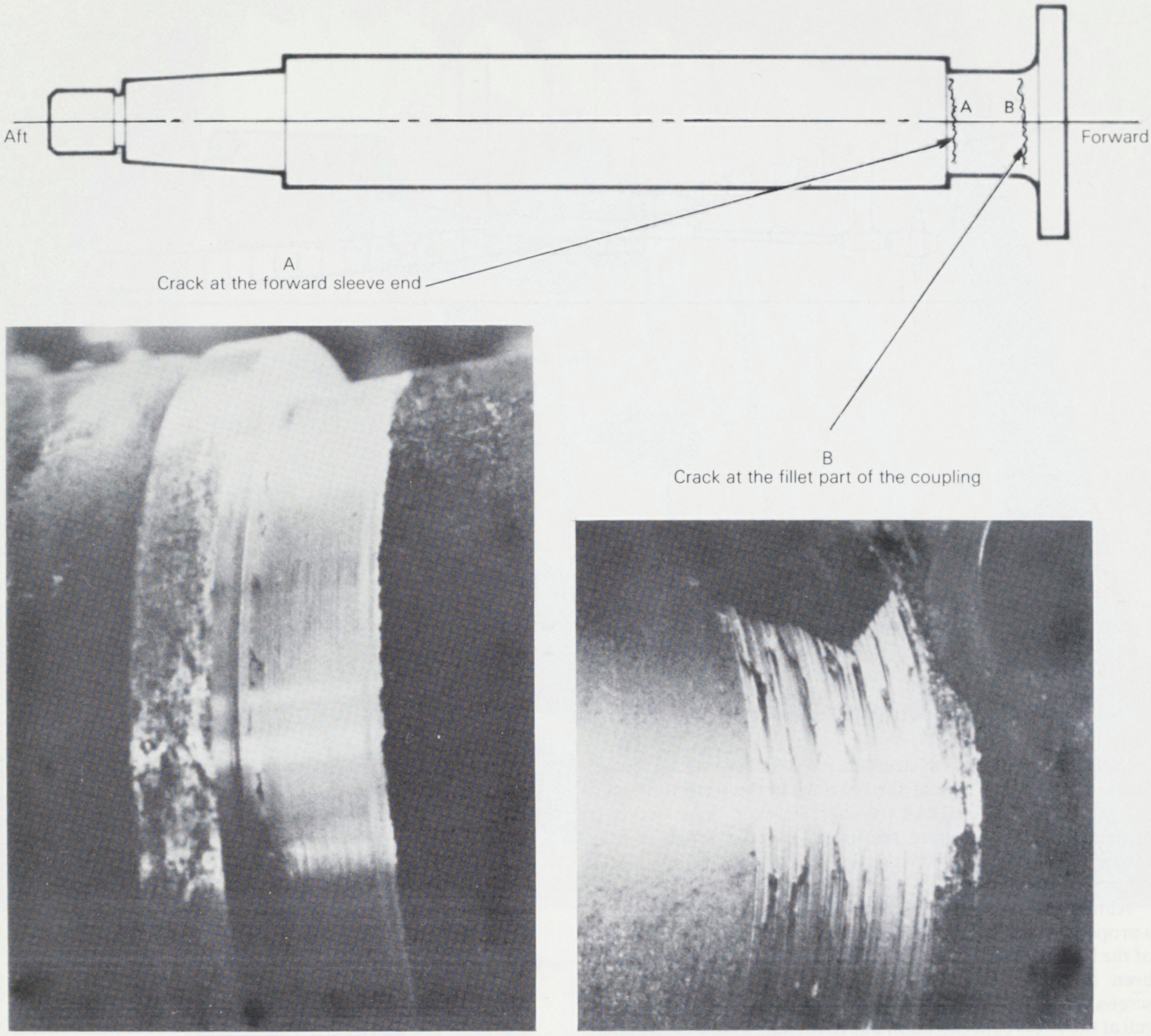


FIG. 26

5.2 Cracked

2,855 kW cargo ship.

At the survey of screwshafts having continuous liners much attention is paid to the condition of the shaft at the top of the cone under the rubber ring, and in cases of doubt a few millimetres are machined from the aft end of the liner before applying magnetic crack detection.

The coupling ends of such shafts should receive equally close scrutiny, because with leaking stern glands pouring sea water copiously over unprotected couplings the conditions are predestined to bring about stress corrosion cracking; the stress at this end of the shaft being torsional. Figure 26 illustrates a case in which the screwshaft was found to be cracked at the forward end of the liner and in the coupling.

5.3 **Bending Fatigue Fracture**

2,984 kW replenishment tanker.

Figure 27 shows a controllable pitch propeller shaft which broke at the forward coupling. The stern tube is fitted with a lignum vitae bush and the ship operates in an extremely hostile environment due to sand bars. She has a history of extremely rapid wear down of the stern bush; renewal of the lignum vitae having taken place at each annual drydocking.

When the screwshaft finally succumbed to the high bending stresses to which it had been subjected, the wear down of the bush was found to be 19.5 mm! (See Fig. 28.)

The Owners have been advised to consider conversion to an oil lubricated stern bush with lip seals.

Fig. 27

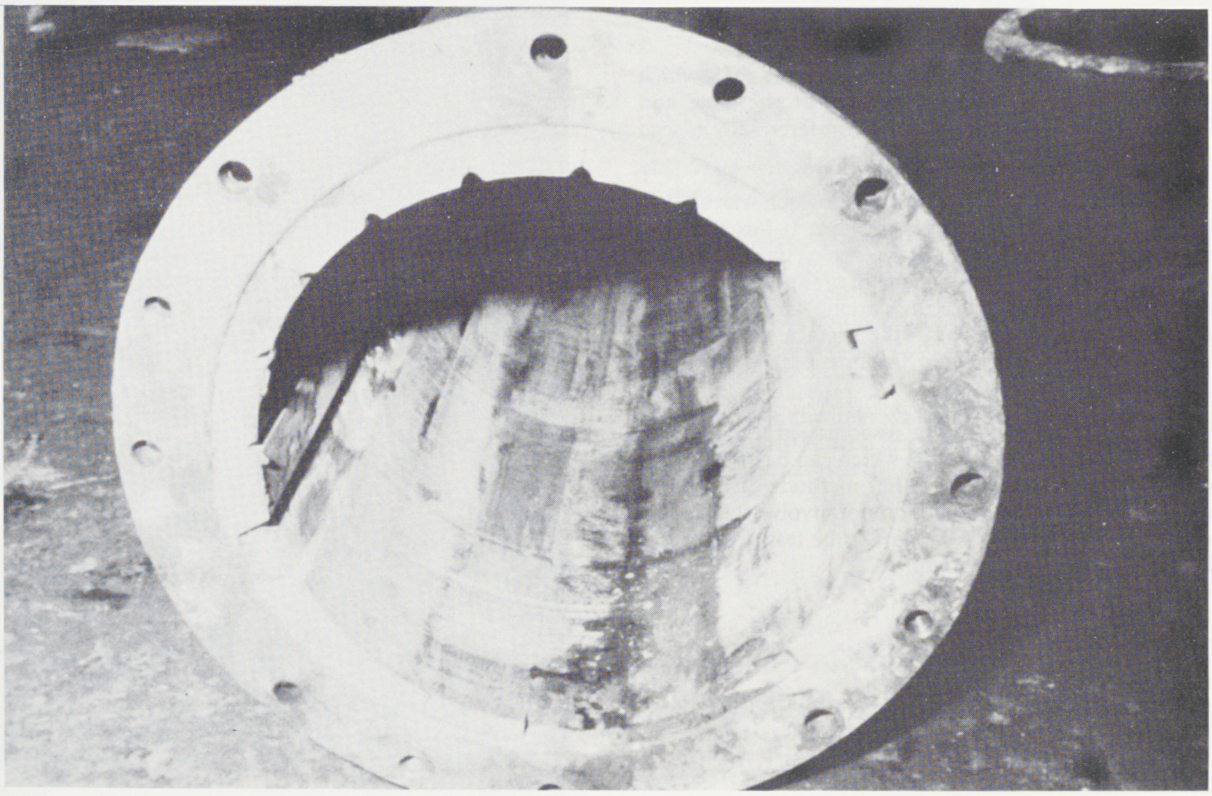


Fig. 28

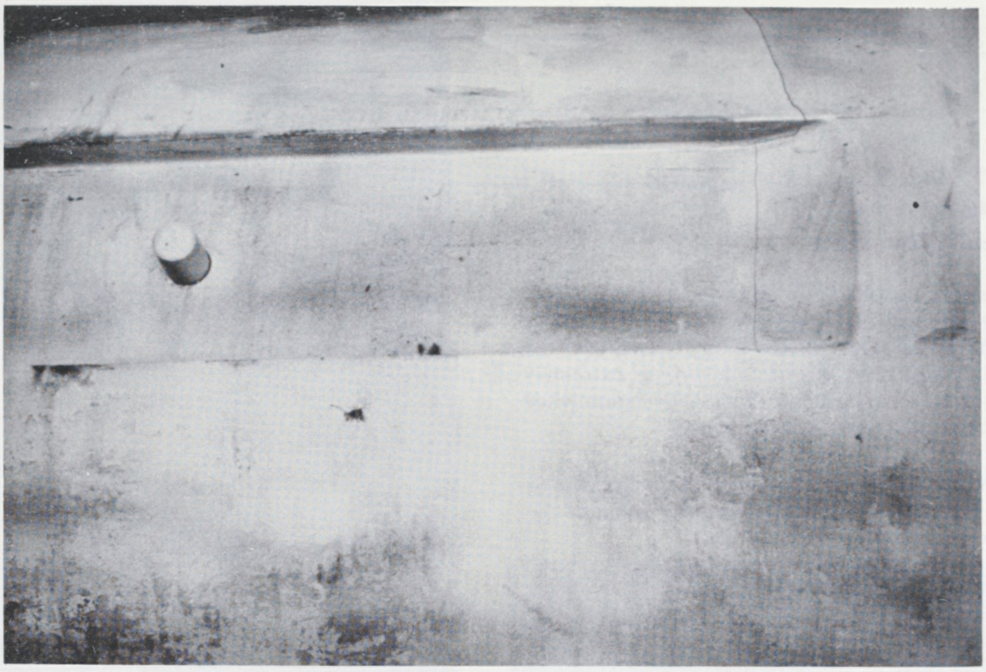


Fig. 29

5.4 **Magnaflux**

Figure 29 shows a crack in the keyway of a screwshaft which originated in the keyway fillet at the top of the cone and extended around the body of the shaft circumferentially as seen in Fig. 30.

Attention is directed to the brass contact which was used as one of a pair for magnetic crack detection. It has been the practise to pass an electric current between such terminals while spraying the magnetic ink. Any movement of the terminal while the current is passing is likely to cause arcing which can create high temperature micro-damage to the surface giving rise to stress concentration and ultimate fracture of the part as a result.

The use of this technique is to be discouraged. Figure 13 in Section 4 shows the excellent results which can be obtained by the use of a permanent magnet. Other methods of magnetic crack detection are available which do not involve the passing of an electric current through the part to be tested and these should be employed as appropriate.

Fig. 30

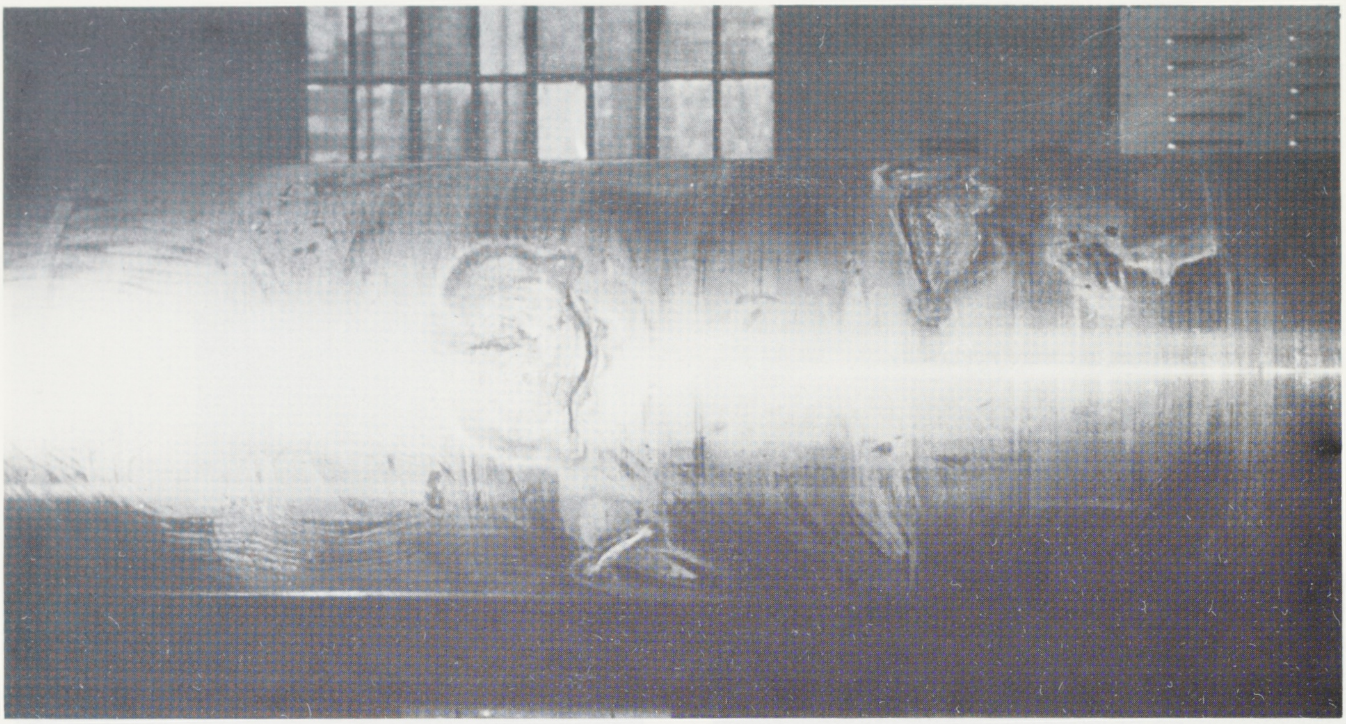


Fig. 31

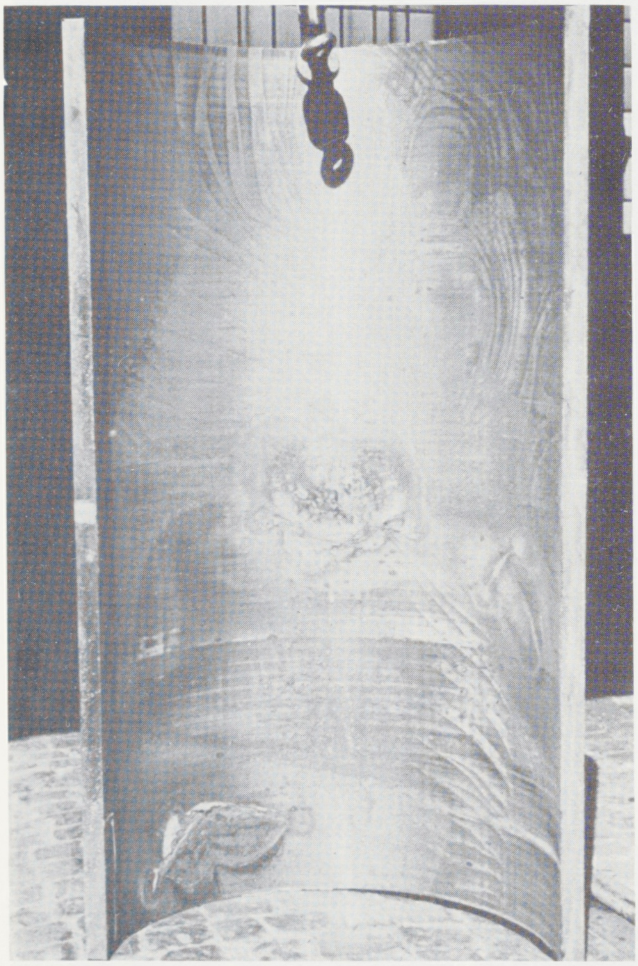


Fig. 32

6. SCREWSHAFT LINERS

6.1 Cracked

Occasionally cracks are found in bronze screwshaft liners as shown in Fig. 31 and suggestions will be made that the cracks should be chipped or ground out and the resulting groove filled up with a sealing compound.

These proposals should be vigorously resisted because experience has shown that in such cases, serious damage will probably have resulted to the body of the steel shaft underneath, due to the establishment of an electrolytic cell in the presence of torsional and bending stress, giving yet another example of stress-corrosion cracking.

In this case, the liner was cut off and the shaft was found to have developed a deep crack following the precise line of the crack in the liner (see Fig. 32).

6.2 Cracked Welds

This screwshaft was fitted with a bronze liner in three sections having two circumferential welds.

During the shaft survey a crack was seen at the side of one of these welds (see Fig. 33). The shaft was placed in a lathe for investigation (see Fig. 34) and after machining the weld material away a very deep crack was exposed in the body of the shaft exactly in line with the crack which had been found in the liner (see Fig. 35).

The liner material was subjected to chemical analysis for lead content and was found to be far in excess of the 0.5% maximum permitted by the Rules to ensure weldability.

FIG. 34

FIG. 33

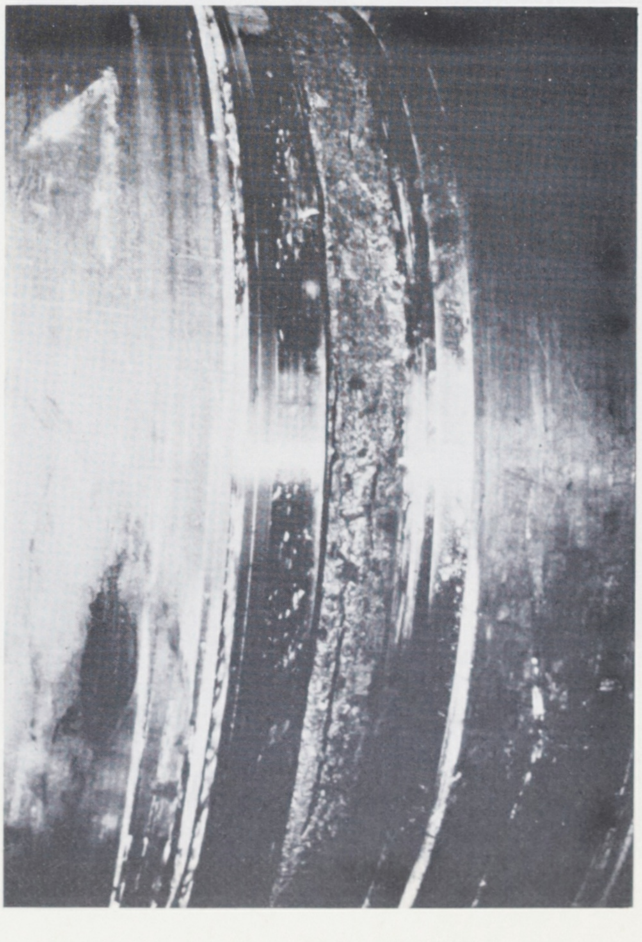


FIG. 35

FIG. 36

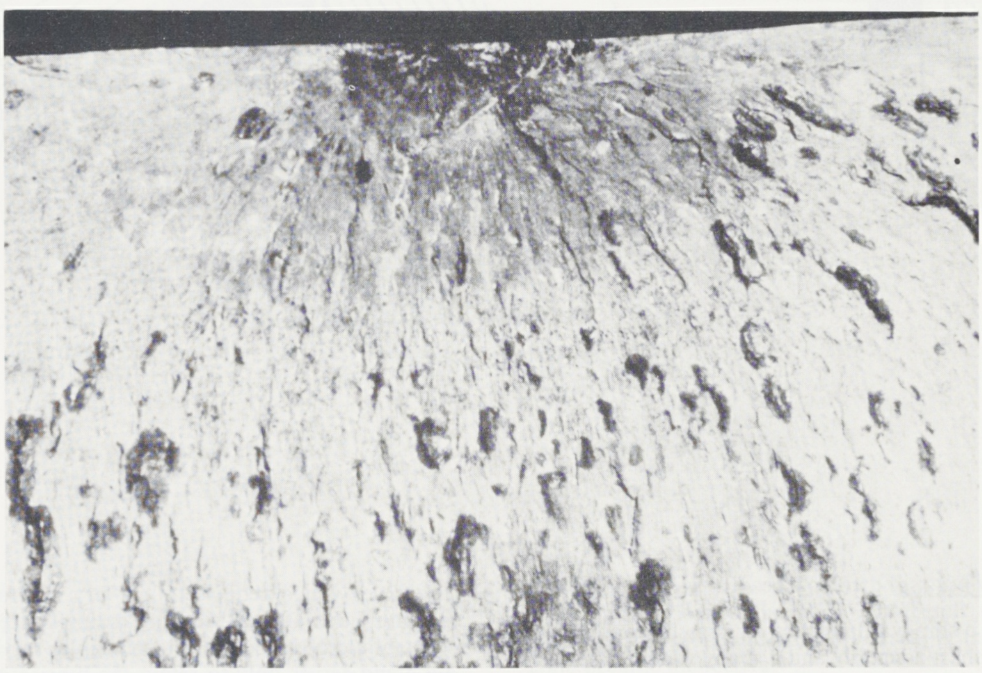


FIG. 37

7. PROPELLERS

7.1 Fractured Blade

Figure 36 shows the fracture face of a broken propeller blade.

The cause of the failure was investigated and proved to be a tiny spot of welding on the blade surface, presumably for 'cosmetic' reasons (see Fig. 37). This introduced a stress concentration in a position of high stress with a disastrous result.

Small surface imperfections on propeller blades are much better dealt with by smooth grinding and blending.

Where it is desired to repair by welding areas damaged by cavitation erosion the Surveyors should refer to the Rules for guidance, and bear in mind that some valuable advice will be available from the propeller manufacturers.

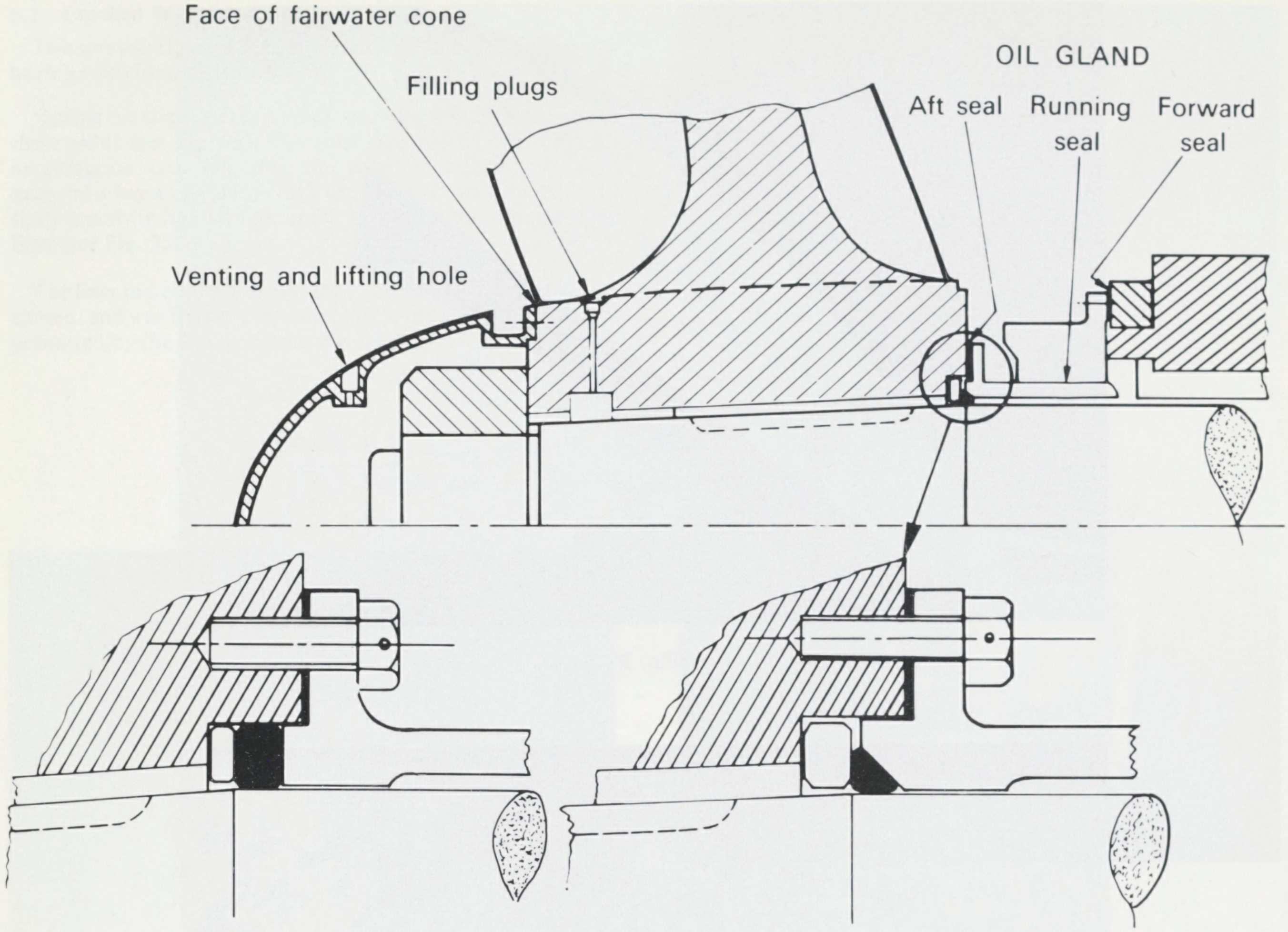


FIG. 38

7.2 Sources of Leakage

Shortly before a ship was launched air pressure was applied to the propeller/shaft assembly and a soapy water test proved most revealing.

In Fig. 38 attention is drawn to the large flat face joints and the holes which require to be very carefully sealed at first assembly and after subsequent maintenance overhauls.

It should be noted that the triangular section seal ring in the oil gland serves only to retain the lubricating oil in the stern tube, whereas the rectangular section ring will also prevent sea water from reaching the top of the screwshaft cone.

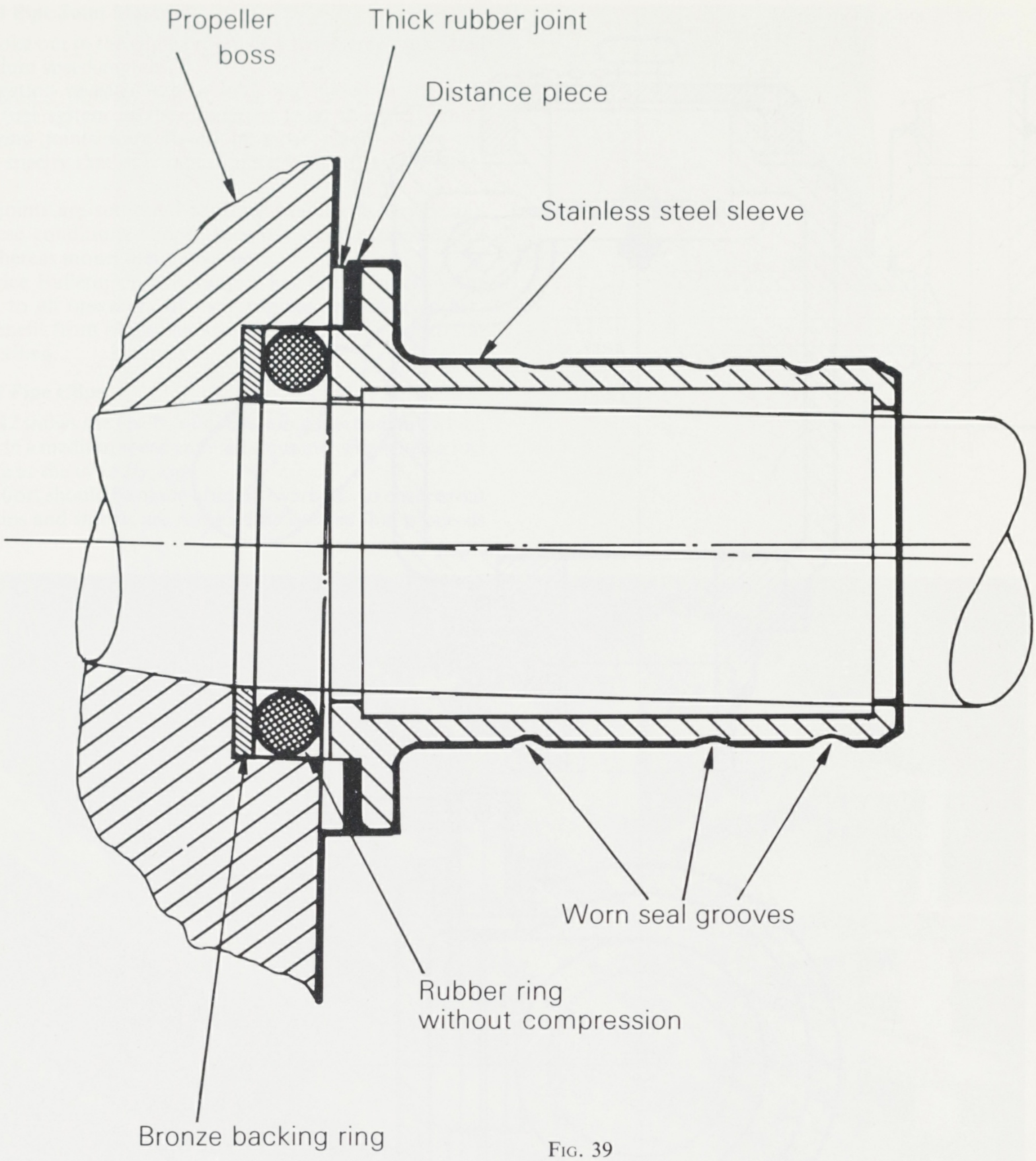


FIG. 39

7.3 **Oil Gland Sleeve**

In order to avoid the expense of machining a worn oil gland sleeve it was decided to move the grooves out of line with the seal rings by placing a distance piece between the sleeve flange and the propeller boss (see Fig. 39).

The idea seems in order, but unfortunately the thickness of the distance piece chosen was such that the flange spigot came out of the recess in the boss. The result was that the true alignment was lost and the rubber seal at the top of the shaft cone became ineffective.

The greatest care should be taken before making any changes to original designs.

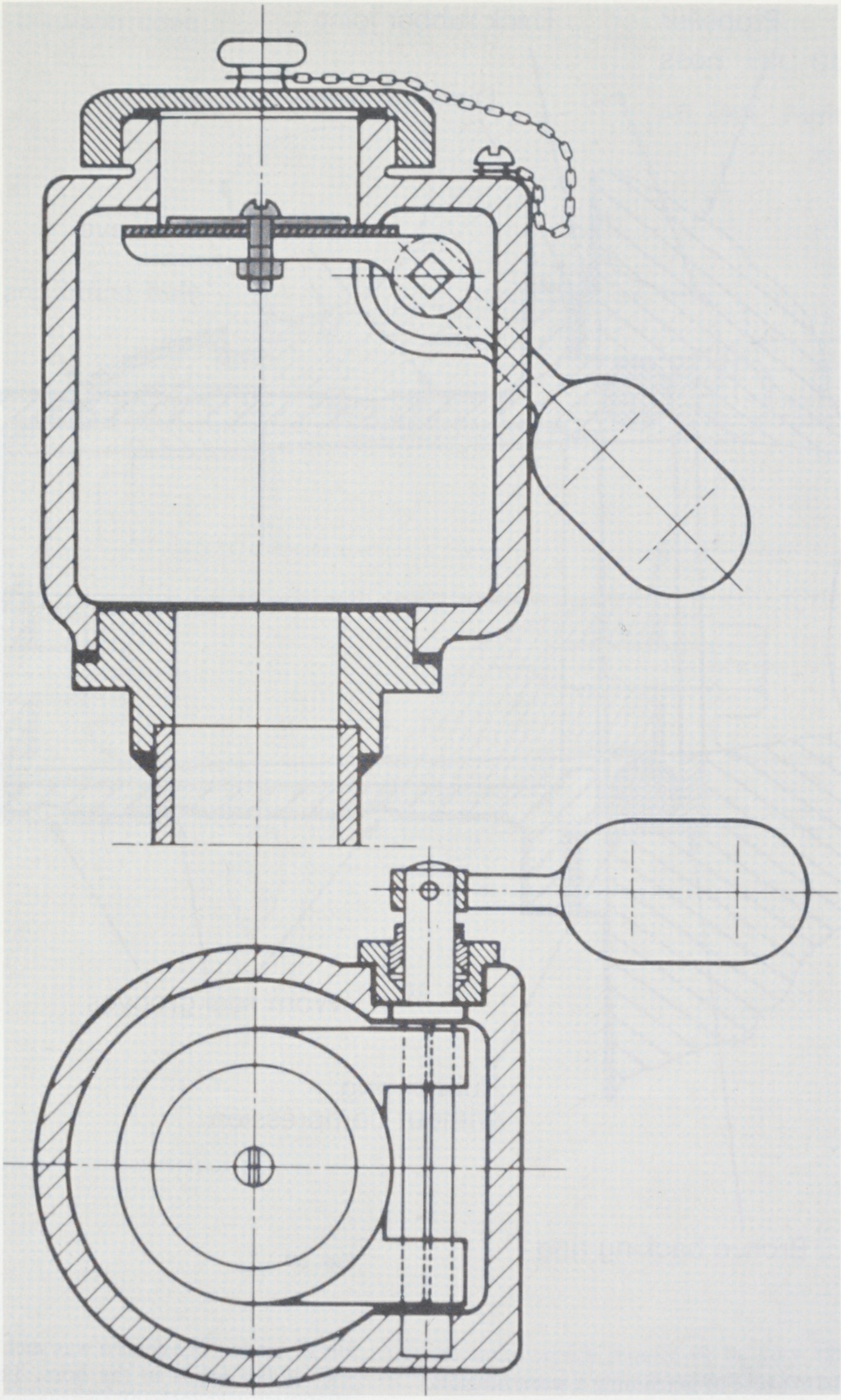


Fig. 40

8. ENGINE ROOM FIRES

8.1 Self-closing Cocks

Short sounding pipes to fuel tanks in machinery spaces are at present permitted by the Rules of the Classification Societies but they are required to be provided with self-closing devices, and if cocks are proposed these are to have parallel plugs.

International discussions are going on with a view to the abolition of short sounding pipes to fuel tanks but in the meantime there are very many at sea, and they should be used with great care especially during bunkering operations.

Figure 40 shows an excellent weighted lever self-closing device through which a fountain of gas oil emerged setting fire to the engine room and causing great damage. There was no personal injury or loss of life because the person concerned was on deck talking to the crew of the bunker barge, and became aware of trouble when gas oil emerged from the air pipes. Only then did he realise the significance of his having lashed the weight in the open position to simplify the task of sounding the tank.

8.2 Fuel Pipe Joint Material

Fire broke out in the engine room of a twin-screw ship fitted with medium speed engines.

Investigation revealed that a joint had failed in the high pressure fuel system at the discharge from the fuel pump. Copper ring joints were found in those places where the designers specify that only monel metal is to be used (see Fig. 41).

These joints are subjected to shock loading in service and under these conditions copper becomes work-hardened and brittle, whereas monel metal does not.

A Service Bulletin on this subject has been issued by the designers to all operators of their engines, but many others should benefit from becoming aware of the danger which has been described.

8.3 Fuel Pipe Clips

Figure 42 shows the results of a severe engine room fire which broke out in a medium speed engined container ship when a fuel pipe broke at the cylinder tops.

Every effort should be made after all overhauls to ensure that all pipe clips and shields are replaced before the ship proceeds to sea.

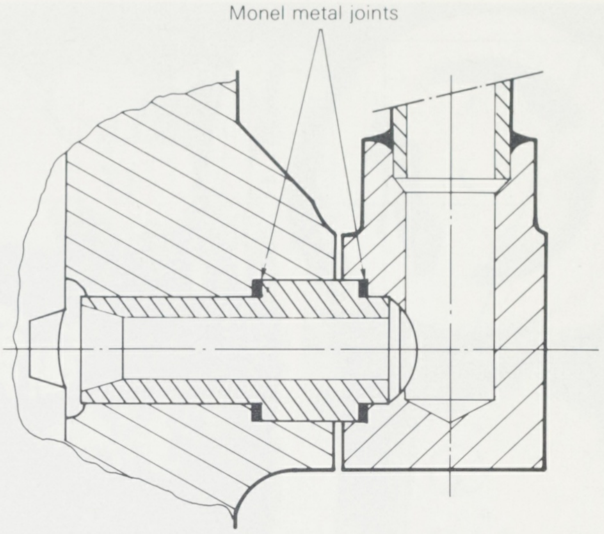


FIG. 41

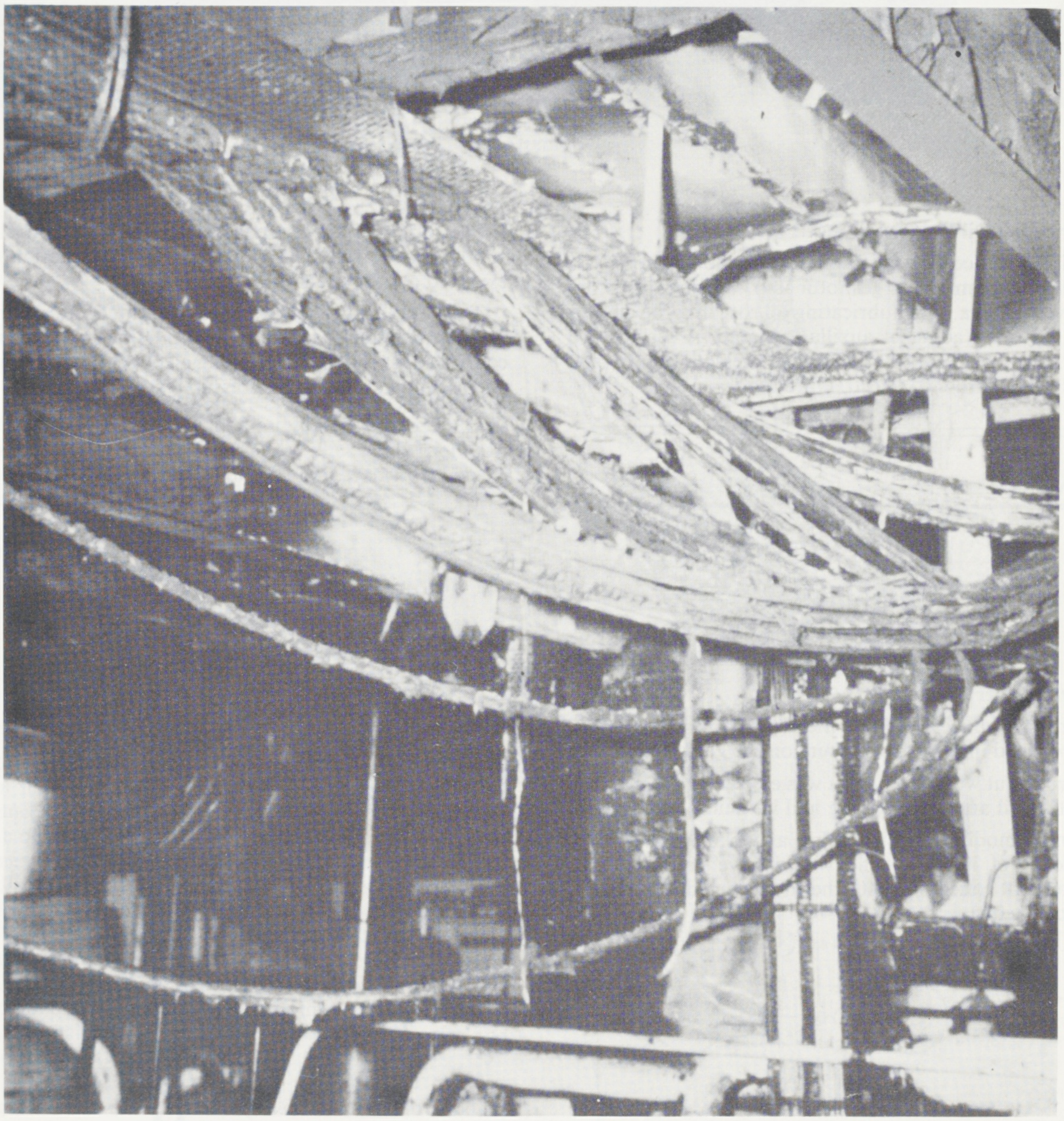


FIG. 42

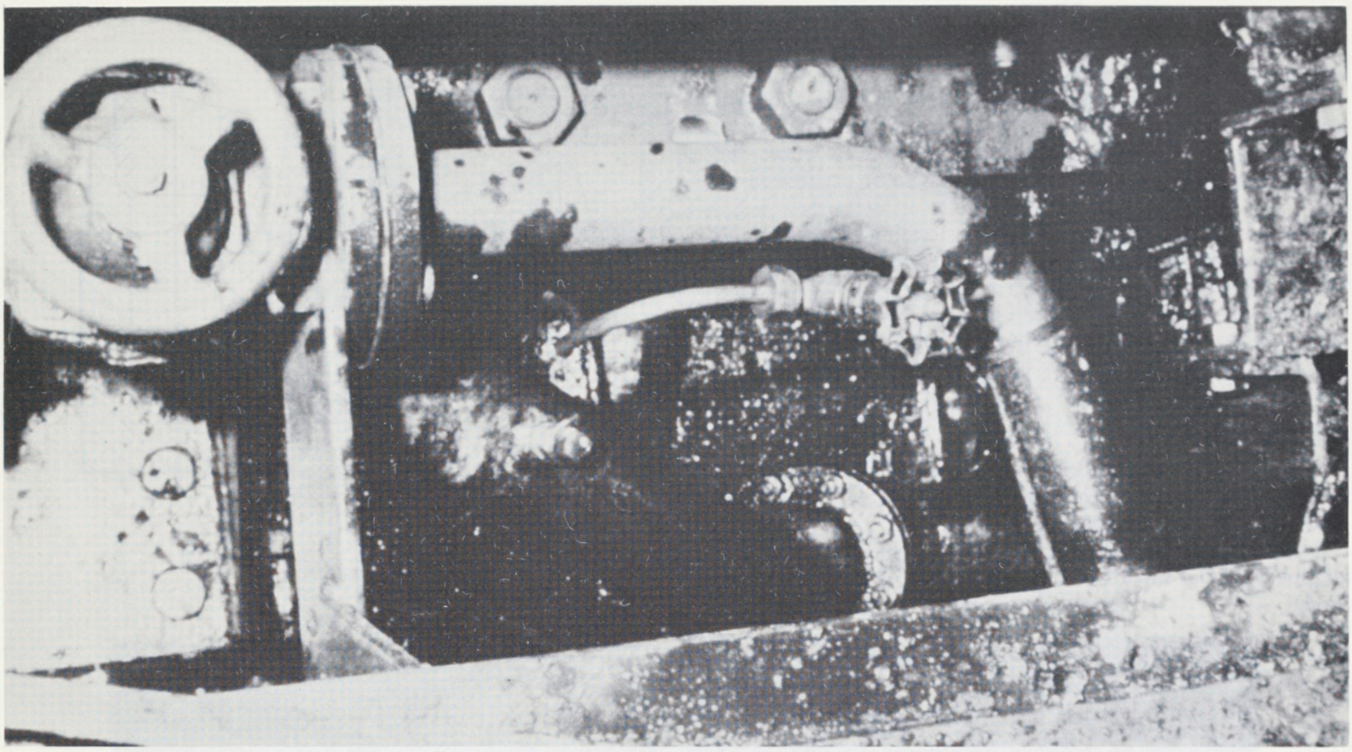


Fig. 43

8.4 **Lubricating Oil Pressure Gauge Pipe**

An engineer noticed oil spreading over a floorplate in the auxiliary engine room of a large motor ship. When he lifted the plate to investigate, a jet of lubricating oil rose into the air and descended upon an adjacent auxiliary engine. A serious fire broke out. Figure 43 shows the copper pressure gauge pipe which had work-hardened and fractured.

The pipe had been connected to one pipe and clipped to another and in these circumstances relative motion could be expected due to vibration.

This would appear to be an ideal application for using a pressure transducer sending a low voltage electrical signal to the control room rather than leading a copper pipe through a long and tortuous route to the pressure gauge.

8.5 **Thermometer Pocket**

In Figure 44 it will be noted that the pocket for the bi-metallic sensor is retained in place by pressure on the gland packing.

A fire broke out when the pocket was ejected by the pressure of lubricating oil after the packing had hardened and shrunk.

The simple modification of fitting a pocket with a small integral collar at its lower end would have prevented this incident, and all concerned with thermometer pockets should be aware of the danger.

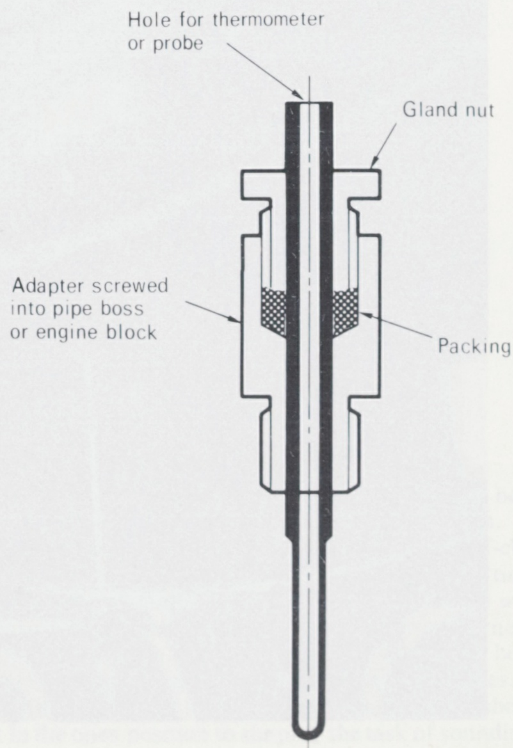


Fig. 44

9. FLOODING

9.1 Sea Water Cooling Pump Discharge Pipe

Figure 45 shows the position of a main S.W. cooling pump in a large bulk carrier.

Halfway across the Atlantic Ocean, midway between the coasts of Brazil and Mauretania and on passage to the Black Sea, a large piece broke out of the cast iron discharge bend from the pump, located below the floor-plates.

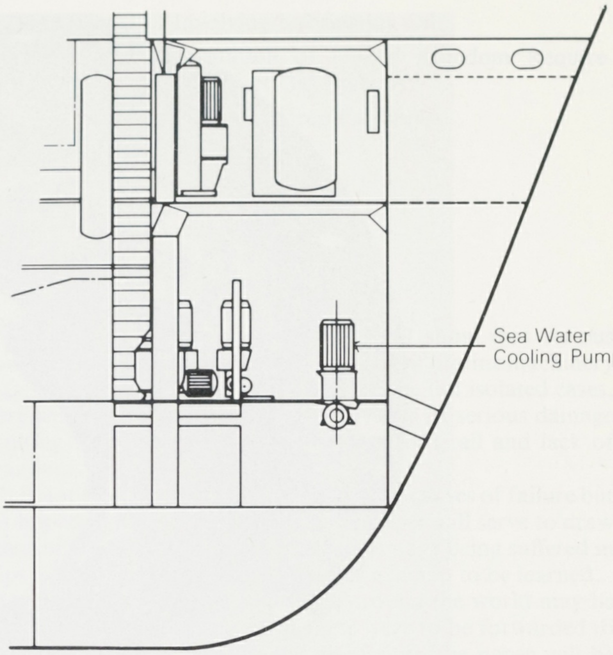


FIG. 45

When the crew realised there was a serious increase in the depth of water in the bilges they attempted to close all sea suction valves and were unable to do so. The engine room was abandoned and the water rose to the level shown in Fig. 46 completely immobilising the ship.

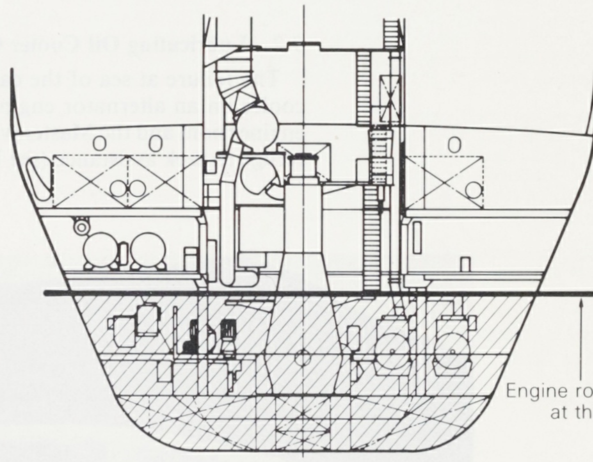


FIG. 46

Despite the fact that the sea suction valves could not be closed (which in itself is a serious reflection upon the standard of maintenance on board), had the crew identified the source of the inrush of water and been thoroughly familiar with the pipe arrangement there were other means available to them to stop the flooding (see Fig. 47). Due to a draft restriction at the intended port of discharge the ship was only partially loaded. Had she been fully laden she would have sunk.

Eventually the ship was towed to a port of refuge for sealing of sea inlets by divers and professional de-watering of the engine room. She was then towed on to discharge her cargo as planned, and back to a Mediterranean port for extensive and expensive repairs.

The importance of maintaining sea inlet and overboard discharge valves in efficient condition cannot be over emphasised.

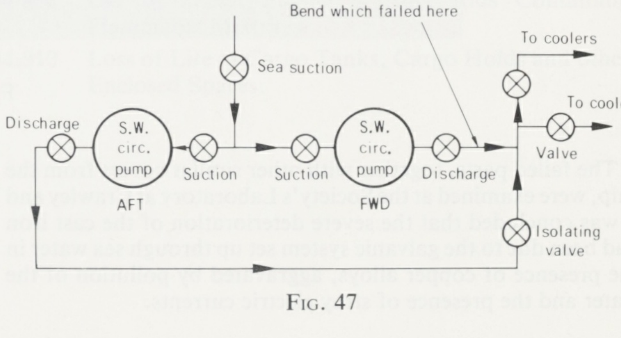


FIG. 47

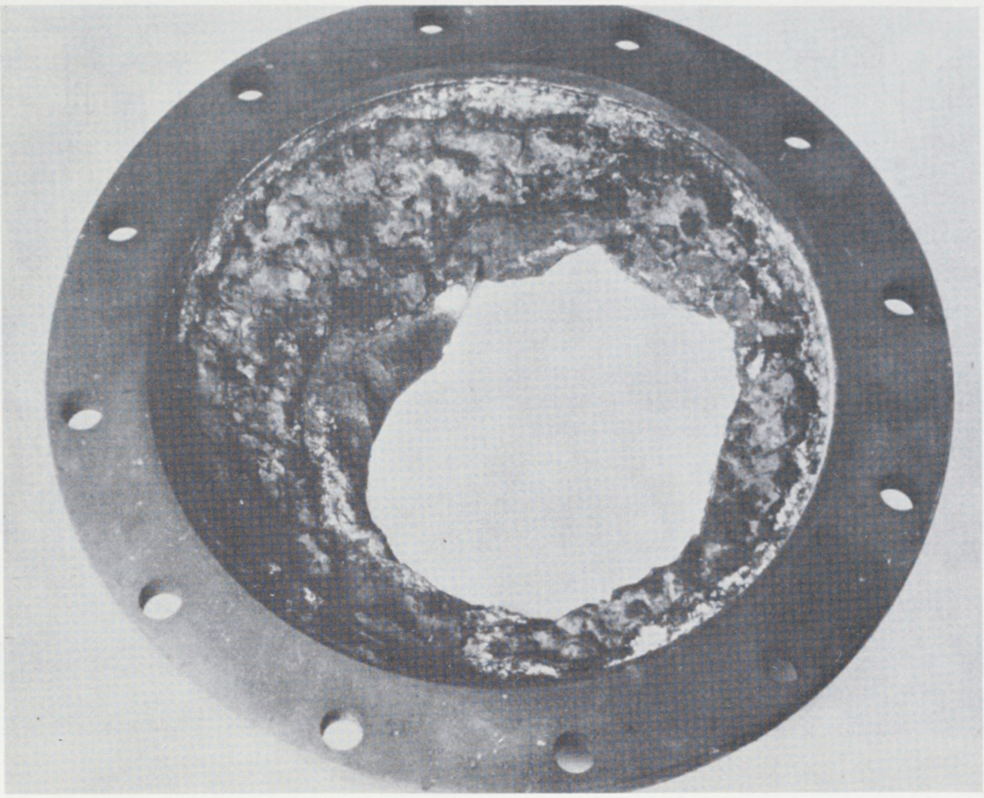


FIG. 48

9.2 Lubricating Oil Cooler Cover

The failure at sea of the cast iron cover of a lubricating oil cooler on an alternator engine caused serious flooding of the engine room and the Master was compelled to put into a port of refuge to seek assistance (see Fig. 48).

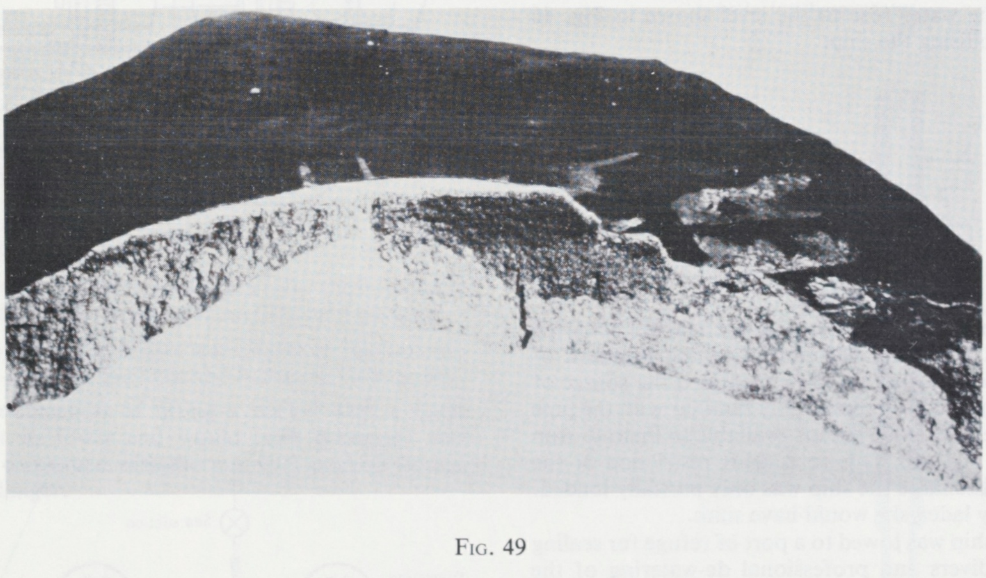


FIG. 49

The failed parts, together with other similar covers from the ship, were examined at the Society's Laboratory at Crawley and it was concluded that the severe deterioration of the cast iron had been due to the galvanic system set up through sea water in the presence of copper alloys, aggravated by pollution of the water and the presence of stray electric currents.

A very important clue to the state of the castings emerged when an apparently undamaged cover was picked up and was found to be unexpectedly light in weight. A tap with a hammer resulted in a large piece falling out (see Fig. 49).

Surveyors and engineers will do well to bear this in mind at surveys and periodical overhauls.

10. REFERENCES

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2. Microbial Attack on Modern Lubricating Oils—Symposium at The Institute of Marine Engineers, June 1977.
3. **Merchant Shipping Notices**

M.474 Explosions in Diesel Engined Vessels.

M.681 Fixed Fire Smothering Gas Installations: Siting Precautions for CO_2 Cylinders.

M.709 Fire Fighting on Small Cargo Ships.

M.443 Fires in Engine Rooms.

M.825 Precautions to be Taken to Prevent the Accidental Release of CO_2 Fixed Fire Smothering Systems.

M.851 Fires Involving Oil Fired Appliances.

M.908 Heating Appliances Burning Solid Fuel.

M.946 Fires Involving Electric Heating or Drying Equipment.

M.971 The Safe Carriage of Coal Cargoes—Emission of Flammable Gases and Spontaneous Combustion.

M.984 Use of Liquefied Petroleum Gas (LPG) in Domestic Installations and Appliances on Ships, Fishing Vessels, Barges, Launches and Pleasure Craft. Explosions, Fires and Accidents Resulting from Leakage of Gas.

M.651 Fires Involving Lubricating Oil.

M.986 Implementation of United Kingdom Requirements for Inert Gas Systems.

M.1022 Fires Involving Deep Fat Fryers.

11. CONCLUSION

A glance at the table of contents will show that serious trouble can arise in quite unexpected parts of marine machinery installations. It is emphasised that these are not isolated cases, there being many more instances on record of serious damage resulting from carelessness, inattention to detail and lack of cleanliness.

It is not feasible to catalogue all possible causes of failure but it is hoped that the cases shown in the paper will serve to draw attention to the fact that much of the damage being suffered in ships is avoidable. Each case contains a lesson to be learned.

On reading the paper, colleagues around the world may be reminded of other cases and, if these were to be forwarded to London as contributions to the discussion, the paper will be greatly enhanced.

Thanks are already due to the many colleagues who have sent photographs either with their reports or in response to requests for assistance, and the help received from Graham Pumphrey, the Technical Illustrator, deserves especial mention.

APPENDIX

The following Merchant Shipping Notices are reproduced with the kind permission of the Department of Trade, Marine Division.

M.707 Fires Involving Low Pressure Oil Fuel Pipes.

M.765 Maintenance and Ready Availability of Fire Appliances.

M.902 Explosions in Boiler Furnaces.

M.750 Prevention of Oil Fires in Machinery Spaces of Ships.

M.852 Use of Diesel Engine Starting Aids Containing Flammable Mixtures.

M.910 Loss of Life in Cargo Tanks, Cargo Holds and other Enclosed Spaces.

Department of Trade — Merchant Shipping Notice No. M.707

FIRES INVOLVING LOW PRESSURE OIL FUEL PIPES

Notice to Shipowners, Shipbuilders, Enginebuilders and Masters

1. A number of serious fires in machinery spaces have originated from the fracture of low pressure fuel oil pipes, operating at nominal pressures up to about 4 bars (58·8 lbsf/in 2) and associated with main propulsion or auxiliary diesel engines operating at above 300 RPM.

2. The low pressure pipes most frequently involved in fires investigated by the Department are the fuel pump suction rail carrying the discharge pressure from a fuel booster pump, pipes connecting the fuel rail to the fuel pumps and small bore copper pipes connected to the fuel suction rail for various purposes. Failures have often been associated with pressure fluctuations within the pipe or vibration from external sources.

3. In the light of this experience these fuel pipes should wherever possible, be located well away from potential ignition sources. It is recognised that choice of location may be limited in many cases but some of the small bore connections mentioned above could be made in safe positions. Where pipe fracture or coupling failure could lead to fuel spraying on a hot surface, for example, the engine exhaust-system, it is recommended that suitable screening arrangements should be provided to deflect the oil to a safe place.

4. Some of the fires investigated, in machinery spaces with limited headroom over the engine tops, have damaged essential electrical cables carried in trays attached to the deckhead over the engine; where there is no alternative route available, consideration should be given to the protection of the cables from fire damage. Such fire protection should take into account the cable rating and the normal heat dissipation requirements.

5. Ship's staff should ensure that any fuel leakage is dealt with promptly and maintain screening arrangements, and pipe securing arrangements in an efficient condition.

Department of Trade,
Marine Division
London
January, 1975

MS 7/3/0969

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C819379 Dd 200468 21M 2/75

Department of Trade — Merchant Shipping Notice No. M.765

MAINTENANCE AND READY AVAILABILITY OF FIRE APPLIANCES

Notice to Shipowners, Masters and Officers

1. It is a principle of fire fighting that all equipment must be maintained in good order and be kept available for immediate use at all times. This applies equally to such equipment as fire extinguishers and hoses as it does to fire pumps and fixed fire extinguishing systems.

2. A number of cases have arisen in which non-portable fire extinguishers have been secured in such a manner that, in an emergency, they could not have been immediately brought into use. The extinguishers concerned were of the 10 gallons capacity chemical foam type mounted either on two wheels or trunnions and supported on a steel foot or leg. Operation of the extinguisher included rotating it from the vertical through 90 degrees to a horizontal position thus mixing the chemical solutions. It has been found that the foot or leg supporting the extinguisher has been adapted as a means of bolting the appliance to the deck in order to prevent inadvertent operation in a seaway. When required in an emergency, the extinguishers could not be released without the use of spanners.

3. It is recommended that extinguishers of this type should be secured by a band type bracket fitted in halves round the body of the extinguisher with a non-corrodible hinge and securing pin. Whatever method is chosen to secure the extinguisher it should be capable of ready release without the use of tools.

4. In other cases, emergency fire pumps have been found to be defective when required in an emergency or in the course of testing for statutory survey. It should be recognised that a defective emergency fire pump would involve the detention of a ship until the pump is repaired or other acceptable arrangements are made.

5. Ships' staff should regularly examine and test all safety equipment to ensure that it can be brought into use immediately in an emergency.

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Marine Division
London WC1V 6LP
June 1976

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DEPARTMENT OF TRADE MERCHANT SHIPPING NOTICE No. M.902

EXPLOSIONS IN BOILER FURNACES

Notice to Shipowners, Superintendent Engineers, Engineer Officers and Crews of Merchant Ships

1. The dangers of boiler furnace explosions caused by accumulations of flammable gases in furnaces following burner defects, especially during flashing up procedures, are recognised and well known. However, the design of modern boilers, while safe in itself if control systems are operating correctly, is such that the consequences of gas explosions caused by defects or negligence are likely to be more dangerous. The recent increase in power and operating pressures also increases the potential hazard. In a recent incident, on a foreign flag vessel, such an explosion caused a failure of the membrane walls which released the contents of the boiler under full pressure resulting in the death of 26 men. In another gas explosion on a British vessel one officer lost his life, due to displacement of the air trunking (further cases are on record).

2. In both of these cases the boilers involved were of normal modern design, being roof fired and fitted with high output burners and membrane walls. In both cases the automatic control system was partially inoperative. Burner logic systems are designed to safeguard the plant and personnel and when operating as designed, are perfectly satisfactory. Nevertheless when the systems are degraded, due to defects or due to manual overriding, extreme care is necessary on the part of the operators to ensure that hazardous conditions do not develop. The remoteness of the burners from control positions and the high throughput of each burner, cause added dangers when flashing-up, or following flame failures, when logic systems are inoperative for any reason. All boiler operators must be completely conversant with the logic system in use on the boiler in their charge and must understand the effect on the protection system of any changes in the logic system, being prepared to take extra precautions when boilers must be fired under such conditions. Operation under such conditions should be avoided whenever possible. Particular attention is drawn to the need to purge the furnace and gas passages with air following flame failure or ignition failure however short the period of failure or prior to any lighting up operation. This is normal good practice, but may not be enforced by a degraded logic system. When using distillate fuels in burners designed principally for heavier fuels these dangers are increased and steam atomisation should not be used. All precautions in the operating manual must be complied with at all times.

3. Instructions for boiler operation, both in instruction manuals and on notices near the boiler, should additionally contain adequate warning regarding extra precautions necessary when operating with degraded logic systems, or with manual or local overrides in use, and operators must be sure they understand all the implications of such instructions and act upon them. These instructions should also state the duration and rate of purge in accordance with the designers burner logic sequence. When the logic system is overridden by manual or local overrides this should be indicated at the control positions so the operator can take due care.

4. Operators should periodically check the condition of igniters and flame scanners, to ensure that they are in good working order. Automatic fuel oil shut offs should, as a routine, be tested to ensure that the fuel valves operate efficiently for fault conditions (e.g. flame failure and combustion air failure). Burners should be lit with fuel oil at the minimum firing rate compatible with flame establishment and operators should not attempt to light a burner immediately after its flame failure, off an adjacent burner which is in service. On no account should boiler safety valve settings be adjusted when the controls are in the automatic mode.

5. Membrane walls are now a common and generally accepted feature of boiler design but as a consequence of this form of construction the furnace is largely enclosed in a rigid shell. An explosive disruption of this shell may cause considerable structural damage to the boiler causing its contents to be suddenly released into the boiler room thus presenting greater danger to personnel. Such boilers are provided with extensive safety devices and alarms which must be maintained at high efficiency and which should not be overridden unless absolutely necessary. Such overriding must be used only with great care and with an awareness of the consequences. Even very small amounts of unburnt fuel entering a furnace can, when vaporised, cause big explosions leading to extensive damage and injuries.

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Marine Division
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PREVENTION OF OIL FIRES IN MACHINERY SPACES OF SHIPS

Notice to Shipowners, Shipbuilders, Engine Builders, Masters and Engineer Officers

(This Notice Cancels Notices Nos. M.439 and M.617)

A number of serious fires have occurred in ships' engine and boiler rooms and the Department of Trade recommends that the precautions for preventing fires described in this Notice should be taken.

OIL IGNITED BY CONTACT WITH HEATED SURFACES

The following cases have occurred of accidental ignition of oil by contact with heated surfaces.

In a foreign-going passenger vessel the overflow pipe from an unpurified diesel oil tank was an open goose neck situated within the engine room. When the tank was inadvertently over-filled, oil poured from this goose neck onto the hot exhaust of an auxiliary engine and ignited. The ensuing fire was soon out of control and the machinery space abandoned. The passengers and some of the crew were forced to abandon the vessel in the ship's lifeboats and the vessel was eventually towed to port for repairs.

A similar incident occurred on a small trawler. It was the normal practice when filling the "stand by" daily service tank to overflow it into the "in use" tank through an overflow pipe. However, in this instance a small sounding plug had been removed from the top of the "stand by" tank, and the excess oil flowed not into the other tank but out of the plug hole and down onto the main engine, where it ignited immediately. The fire was controlled by the crew using normal equipment and techniques, but the chief engineer received extensive burns about the head and shoulders which necessitated a prolonged stay in hospital and a skin graft.

Overflow incidents of this type often occur during bunkering. In one case on a 250,000 ton steam turbine tanker the gas oil tanks were so arranged that the service tank overflowed into the double bottom tank. However, during bunkering both these tanks became full and excess gas oil flowed up their common vent pipe, which terminated with a goose neck inside the funnel casing. This oil was partially retained in the funnel where it was in contact with the boiler and auxiliary diesel exhausts, and part escaped via a small scupper onto the funnel deck where it saturated the lagging of hot pipes. The result was a fire in both spaces, showering burning gas oil into the engine room starting secondary fires.

In another case, a fuel line was fitted with duplex filters with a change-over cock, the handle of which also acted as a safety device which should have made it impossible to open up the filter under pressure. When examined it was found that the change-over handle could be put on the wrong way round, i.e. the handle could indicate and protect one filter when in fact the other filter was under pressure. In this case, the filter indicated as being out of use was being slackened off preparatory to cleaning and the resulting spray of fuel oil striking the hot exhaust caused an immediate and serious fire. In somewhat similar circumstances involving a lubricating oil filter, a fire resulted in the death of one of the ship's officers.

Lubricating oil fires are potentially as dangerous as those from fuel oil. In one incident, an explosion was caused by piston cooling oil being discharged from a fractured piston rod sleeve into one of the main engine cylinders and thence into the exhaust manifold, where it formed an explosive mixture with scavenging air. A section of the manifold was shattered and flaming oil was sprayed about the forward end of the engine room and all over the main switchboard.

A 34-gallon froth extinguisher was used on the rapidly developing fire without much effect and the situation was beyond immediate control. The main engines were stopped but it was impossible to remain in the engine room, and the chief engineer and his staff operated the appropriate remote controls to stop the auxiliary machinery and shut off all fuel supplies to the machinery. All openings to the engine room were closed and CO_2 gas was injected to smother the fire. Six hours after the outbreak, the chief and second engineers were able to enter the engine room from the tunnel door and put out all smouldering fires with hoses connected to the emergency pump.

A number of serious fires in machinery spaces have originated from the fracture of low pressure fuel oil pipes, operating at nominal pressures up to about 4 bars (58·8 lbsf/in^2) and associated with main propulsion or auxiliary diesel engines operating at above 300 RPM. The low pressure pipes most frequently involved in fires investigated by the Department are the fuel pump suction rail carrying the discharge pressure from a fuel booster pump, pipes connecting the fuel rail to the fuel pumps and small bore copper pipes connected to the fuel suction rail for various purposes. Failures have often been associated with pressure fluctuations within the pipe or vibration from external sources.

Numerous cases similar to those above are recorded in the Department's casualty records and many could have been easily avoided. In order to prevent similar accidents on new or existing ships the following precautions are recommended:

(1) **Overflow Arrangements**

(*a*) Steps should be taken to ensure that overflow arrangements do not permit the overflowing oil to come into contact with boilers, hot engine parts, or other heated surfaces where it might be ignited. Where oil tight flats are fitted with drain pipes, these should preferably be open pipes; but readily accessible cocks would not be objected to and may even be necessary where inter-flooding of two separate watertight compartments could occur through the drains;

(*b*) Overflows from settling tanks and daily service tanks should be led back to the storage tanks or to an overflow tank. An alarm device should be provided to indicate when the tanks are overflowing.

2

(2) **Sounding Arrangements**

(*a*) Care should be taken to see that the sounding arrangements or oil level indicating gear on settling tanks and daily service tanks are such as will not permit the escape of oil should the tanks be overfilled;

(*b*) Oil level indicators should be of a type which will not allow oil to escape in the event of damage to them. It is preferable that they should be of a type which does not require piercing of the lower part of the tank. Round gauge glasses should not normally be fitted to oil tanks, but suitably protected gauges having flat glasses of substantial thickness and self-closing fittings may be allowed.

(3) **Fuel Oil Pipes**

(*a*) Oil pressure pipes which are used for conveying heated oil should be placed in conspicuous and well lit positions above the platform;

(*b*) Small bore flexible pipes intended to convey oil should be made of suitable fire resisting material. All other pipes should be made of steel or other suitable material;

(*c*) Where pipe fracture or coupling failure could lead to fuel spraying on a hot surface, for example the engine exhaust-system, suitable screening arrangements should be provided to deflect the oil to a safe place.

(4) **Oil Fuel Units**

(*a*) Where oil which might escape from any oil fuel pump, filter or heater may come into contact with boilers or other heated surfaces, provision should be made to prevent this by the erection of suitable screens;

(*b*) Save-alls or gutters should be provided under the oil fuel pumps, heaters or strainers, to catch oil leakage or oil that may be spilled when any cover or door is removed, and likewise at the furnace mouths to intercept oil escaping from the burners;

(*c*) Any relief valve fitted to prevent overpressure in the oil fuel heater should be in closed circuit;

(*d*) Master oil valves at the furnace fronts should be of the quick closing type fitted in conspicuous and readily accessible positions. It is recommended that they be painted bright red for identification in an emergency;

(*e*) Provision should be made to prevent oil from being turned on to any burner unless it has been correctly coupled to the oil supply line, and to prevent the burner being removed before the oil is shut off;

(*f*) A suitably mounted plan of the oil fuel arrangements should be furnished for the guidance of the engineer officers.

(5) **Means of Escape**

There should be at least two means of escape from spaces containing boilers or machinery.

FURTHER PRECAUTIONS

In the interests of safety, owners of cargo ships should arrange that the oil fuel installations comply generally with the Department of Trade requirements in regard to such installations on passenger ships.

Serious fires have often originated from apparently insignificant causes such as burning oil running out of the furnace fronts on to the tank top, or a spray of oil from either a defective gland or joint or a fractured pipe, not perhaps readily noticeable but easily ignited. The conditions which are most dangerous and which it is most important to avoid are conditions which will allow a small fire to spread to waste oil, in the bilges or on double-bottom tank tops, and so get rapidly out of control. Cleanliness is essential for safety and a high standard of cleanliness must be maintained.

Woodwork or other readily combustible material should not be used in boiler rooms and machinery spaces where oil fuel is used. No combustible material should be stored near any part of the oil fuel installation. Bituminous or similar flammable compounds which give off noxious fumes on combustion should not be used in boiler and machinery spaces.

Special attention should be given to the positions and condition of the fire extinguishing appliances including hydrants, hoses and spray nozzles, fire extinguishers, the means for closing the machinery spaces to exclude air in a fire and the means for remote control of fixed fire extinguishing installations and of oil fuel valves.

Some of the fires investigated, in machinery spaces with limited headroom over the engine tops, have damaged essential electrical cables carried in trays attached to the deckhead over the engine; where there is no alternative route available, consideration should be given to the protection of the cables from fire damage. Such fire protection should take into account the cable rating and the normal heat dissipation requirements.

Change-over cocks and their safety devices associated with duplex filters in fuel and lubricating oil systems should be designed and maintained to ensure that the working filter cannot be opened up inadvertently.

Ship's staff should ensure that any fuel leakage is dealt with promptly, and should maintain screening arrangements and pipe securing arrangements in an efficient condition.

As the froth making liquids of chemical extinguishers are more likely to deteriorate at higher temperatures, those extinguishers should be kept in the coolest practicable places.

Department of Trade (MS 2/1/0131)
Marine Division
London WC1V 6LP
March, 1976

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DEPARTMENT OF TRADE MERCHANT SHIPPING NOTICE NO. M.852

USE OF DIESEL ENGINE STARTING AIDS CONTAINING FLAMMABLE MIXTURES

Notice to Shipowners, Fishing Vessel Owners, Engine Builders, Masters, Skippers and Engineer Officers

A serious accident occurred recently on a small diesel-engined vessel, not of United Kingdom registry, as a result of which one man died and three others suffered severe burns. When the engine, arranged for compressed air starting, was being started an explosion occurred in one of the cylinders. The explosion smashed the cylinder and caused a severe fire in the engine room. The fire was fed by diesel oil from the broken fuel main and intensified by escaping compressed air.

The primary cause of the explosion was determined by the investigating authority to have been the introduction into the air intake manifold, by aerosol spray, of an excessive quantity of a fluid sometimes used for assisting the starting of diesel engines.

All persons concerned with the operation of diesel engines are advised to bear in mind the dangers that can arise from the use of volatile, low flash point starting fluids in engines, particularly those which are started by admission of compressed air to the cylinders.

Regardless of the engine starting arrangements, such fluids should always be used in accordance with makers' instructions but never at the same time as cylinder or manifold heater plugs are being used, or when the engine is hot.

Marine Division
Department of Trade
London WC1V 6LP
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DEPARTMENT OF TRADE MERCHANT SHIPPING NOTICE NO. M.910

LOSS OF LIFE IN CARGO TANKS, CARGO HOLDS AND OTHER ENCLOSED SPACES

Notice to Owners, Masters, Officers and Crew Members of all Merchant Ships and to Shipbuilders

1. Within the last few years a number of seamen have lost their lives in cargo tanks, cargo holds and other enclosed spaces.

2. In one incident seven men were killed when they were overcome in the cargo tank of a product tanker. Initially a crew member entered the tank, which contained a few feet of slops comprising tallow, vegetable oils and seawater, prior to the commencement of a tank washing operation. This was contrary to normal procedures because the tank had not been ventilated nor had the atmosphere been tested to ascertain whether it was safe to enter. When it was realised that the crew member was in some difficulty and before it was appreciated that this was because the atmosphere in the tank was unsafe, six other crew members had rushed into the tank to assist instead of following the established and practised emergency procedures for a tank rescue. It was later concluded that the atmosphere was not only deficient in oxygen but contained quantities of other gases generated by the residue. Despite a determined rescue attempt by the remaining crew members wearing breathing apparatus, all seven men lost their lives.

3. Two other incidents occurred on bulk carriers. In the first incident a crew member unsuspectingly entered an unventilated cargo hold that contained various quantities of timber, steel and general cargo loaded some two months earlier. He was seen to collapse and the three men who rushed in to help also got into difficulties because the atmosphere was deficient in oxygen. A rescue attempt was mounted by crew members wearing breathing apparatus but only one of the casualties survived. In the second incident a shore official and four crew members entered a hold containing pig iron loaded three weeks earlier. The ventilators for the hold had been kept closed during the voyage in anticipation of rough weather and the hold had not been ventilated prior to entry. The men were well down into the hold when they experienced difficulties due to the oxygen deficient atmosphere. Although every effort to rescue them was made by crew members using breathing apparatus only one of the five who entered the hold survived. Fortunately no additional lives were lost in this case due to reckless entry by unprotected personnel.

4. In another incident four senior crew members on board a liquefied gas carrier entered one of the double bottom tanks from the duct keel. While they were in the tank one of the men collapsed. Two men remained to help him while the other went to summon assistance. Because no one had been instructed to stand by at the tank entrance and because no safety equipment

was kept ready for immediate use in the event of a situation of this type developing, it proved difficult to mount a rescue attempt and the three men in the tank all lost their lives. Subsequent investigation showed that the tank had not been properly ventilated and that inert gas had leaked into the double bottom tank from a known defect in the bulkhead separating the tank from an adjacent void space.

5. All the above incidents have been described in detail to illustrate the following points.

(*a*) The atmosphere in any enclosed space may be incapable of supporting life. It may be lacking in oxygen content and/or contain flammable or toxic gases and should be considered unsafe unless it has been thoroughly ventilated and properly tested.

(*b*) An unsafe atmosphere may be present in any enclosed or confined space including cargo holds, cargo tanks, pump rooms, fuel tanks, ballast tanks, fresh water tanks, cofferdams and duct keels. Furthermore, it should never be assumed that precautions need not be taken for holds or tanks containing apparently innocuous cargoes.

(*c*) An enclosed or confined space should not be entered unless a "permit-to-work" or similar authority has been obtained.

(*d*) Any one who enters an enclosed or confined space to attempt to rescue a person without first taking suitable precautions not only unnecessarily risks his own life but will almost certainly prevent his colleague being brought out alive.

6. The "Code of safe working practices for merchant seaman" copies of which should be on board all ships, contains detailed advice on entering enclosed or confined spaces. The warnings contained in the Code should be heeded and the recommended procedures followed.

7. It is essential that there should be clearly laid down procedures for entering enclosed or confined spaces—preferably in the form of a "permit-to-work"—to ensure that all the necessary safety measures and precautions are taken.

8. The Code recommends that oxygen testing equipment should be carried on board all ships. Its use, maintenance and regular calibration in accordance with the manufacturer's instructions is strongly emphasised. Additional information on entry into tanks and enclosed spaces on ships carrying dangerous chemicals in bulk is contained in Notice No. M.576.

9. Investigations into incidents involving loss of life have shown that in some of the cases there were no established rescue procedures for dealing with accidents in enclosed or confined spaces. Procedures for dealing with such incidents should be formulated where they do not already exist. Regular drills should be conducted to simulate the rescue of a crew member or life sized dummy from an enclosed or confined space—the space having been proven safe for the exercise. These drills would bring all the emergency procedures into use including, where appropriate, the use of breathing apparatus and lifelines by the rescuers, the control of their air supplies and the provision of replacement air supplies, the lowering of a resuscitator and a stretcher, the rigging of portable hoisting equipment over suitable openings, and the recovery of the "unconscious person" to prove and practise the formulated emergency procedure.

10. When breathing apparatus is being used difficulty is sometimes experienced in gaining entry into enclosed or confined spaces due to the restricted size of the openings. Similar difficulties are experienced in recovering an injured or unconscious person from such spaces, or from a space with restricted access leading to another enclosed space. It is recommended therefore that with new tonnage, access hatches to or manholes or openings in enclosed or confined spaces should be of a suitable size to permit entry by a person wearing breathing apparatus and to allow the recovery of an injured or unconscious person. Furthermore the access hatch, manhole or other opening should be positioned, whenever possible, to enable an unobstructed recovery of the injured or unconscious person from the lowest part of the space.

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SINE PRÆJUDICIO

Lloyd's Register Technical Association

Discussion

on

Mr. R. F. Munro's Paper

SOME MARINE MACHINERY FAILURES AND THEIR CAUSES

Paper No. 3. Session 1982-83

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Any opinions expressed and statements made in this Discussion Paper are those of the individuals.

Hon. Sec. J. S. Carlton
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. R. F. Munro's Paper

SOME MARINE MACHINERY FAILURES AND THEIR CAUSES

DISCUSSION

From Mr. D. Rennie:

The paper sets out to illustrate the penalties which are paid for bad design and poor maintenance, also the lessons to be learned by case study.

The collection of machinery failures presented does indeed show the serious consequences which could well have been avoided if more attention had been paid to detail. The paper should interest all our colleagues and is a useful supplement to the Noteworthy Defects List (N. D. L.).

It may be my training in T.I.D. which prompts the general comment that most of the cases lend themselves to further investigation to ascertain the root cause of failure. Case 2.2 rightly comments on the stress concentration at the tenon root but one wonders if the vibratory stresses were not a little high for this particular row of blades due to a steam excited clamped pin mode of vibration. The pattern of failure in the various blade packets may have given a clue.

Case 4.2 is interesting, where in the two years of operation the crankpin would have been subjected to a sufficient number of stress cycles to have caused failure if the fatigue limits had been exceeded.

One must ask the question—what happened to increase the stress levels?

From Mr. R. Leach:

Mr. Munro's paper will I am sure be widely read with deep interest by all Engineer Surveyors in the field, and I hope, by many of our Ship colleagues who are increasingly becoming involved in engine work. It is mainly by learning of the failures that occur in service, their causes and remedies, that experience is gained by our Surveyors and indeed we all look upon this as one of the most interesting aspects of our work. It was in recognition of this fact that the Noteworthy Defects List was wisely introduced in 1971 and has remained a source of valuable confidential information for our Surveyors ever since. It is to be hoped that the Noteworthy Defects List will continue to be issued on this unique basis for many years to come.

When I joined the Society many years ago papers were frequently written on such practical subjects as that which we have enjoyed tonight.

I have a copy of a classic paper written in 1948 by Alexander Watt very simply called "Notes on Screwshafts" in my possession. In this he describes defects very similar to those illustrated in Mr. Munro's paper—the significance of cracks in bronze liners on screwshafts and the effects of failure to ensure that sea water does not penetrate to the vulnerable area at the large end of the screwshaft cone causing corrosion fatigue cracking—are cases in point. Surely as these problem areas and their hazards were well understood by the Society's Surveyors in 1948 and also in 1938 and 1928 for that matter, it is reasonable to expect that today's Surveyors will have gained sufficient knowledge so that the significance of such defects is fully appreciated. Regrettably, as Mr. Munro's paper has shown, the situation leaves a lot to be desired—is it a case of familiarity breeding contempt or is it a fact the lessons learned by our fathers and grandfathers have been forgotten today?

It is clear that, each decade, the newly appointed Surveyors to the Society need to be reminded of the lessons learned by their predecessors and this can best be done, in my opinion, by adequate training.

In Mr. Munro's first paragraph he emphasises that his paper consists of cases assembled from Surveyors' reports submitted to Headquarters, and I in turn would like to stress how important it is that we at Headquarters should continue to receive such clear and concise reports supported where necessary by Surveyors' sketches, and where possible photographs. It is only by this means that we will be able to collect the data that will enable us to continue to advise our colleagues in the field of the problems currently being experienced and of the solutions to them, and in addition, to give adequate training to our newly-appointed colleagues. Encouragement should therefore be given to our Surveyors to maintain and where necessary improve the standards of report writing. The mere gathering of failure statistics will in no way replace the information that experienced Surveyors can and do submit to this Office, much of which is used to good effect in providing the evidence to support amendments to the Rules and in providing material for training purposes.

The illustrations that we have been privileged to see tonight, coupled with the descriptive matter that is contained in the paper, will serve to impart information to the Surveyors in a far more acceptable and comprehensible manner than the publication of statistics, such as "the incidence of cracked and broken shafts and liners per hundred years of service 1.18"—this might send the statisticians into flights of ecstasy but the practical Surveyor who needs to know the trend in machinery failures fails to be impressed by such figures.

From Mr. T. E. Larmont:

Mr. Munro has given us a paper which I'm sure will be read with a great deal of interest but in particular by those Surveyors actively involved in the field. What I liked so much about this paper was the large number of photographs of actual defects. Photographs have a much greater impact than the written word and I feel sure that Surveyors will welcome them and when they meet up with similar items in the future they will remember the photographs.

The paper is similar to the information which was published for the "Noteworthy Defects List" which I am sorry to see has not been so prominent of late. This was a very good idea and I would like to see it continue and if possible reproduce the same good quality of photographs and sketches that we see in this paper.

Mr. Munro has chosen these photographs because as he says each one has something to tell and a lesson to be learned. I would like to add some further comments to some of the photographs if I may:

Page 4, Fig. 4 shows damage as the result of mechanical contact but a similar damage can be caused by erosion and graphitisation of the material and is well known to Surveyors. A word of caution should not come amiss here when considering a repair. It is commonly thought that this can easily be repaired by plastic compounds or epoxy resins. It should be pointed out however that this does not replace strength and can only be considered a temporary repair. The metal below the filler material continues to deteriorate unseen and can eventually result in some serious defect similar to the one shown on page 28, Fig. 48.

The photographs on page 6 remind me of what can be found at large steelworks where crankshaft forgings and steel castings are produced. The photographs show failure due to unauthorised welding in the fillet area but there are many cases where

minor defects appear in this area during the machining process due to the fact that this particular area is also sensitive in castings. It is very difficult to bring yourself to reject a large casting of this importance for a very minor casting defect like porosity and there is a great deal of pressure on the Surveyor to accept this or a repair of some sort. Unfortunately there is no choice since a repair in the fillet is out of the question and if it cannot be removed by machining or perhaps some slight local grinding then it must be rejected, anything else is inviting a failure.

Page 8, Fig. 13 will I'm sure be of great interest to many Surveyors. This particular type of cracking is becoming quite commonplace with the advent of the medium speed diesel engine and thin wall bearings. Loss of surface metal of these bearings usually causes serious overheating of the surface of the crankpin or journal with consequential heat cracks of this nature, sometimes quite deep and, in the case of surface hardened pins the full depth of case hardening at least. We in head office receive frequent requests for the minimum diameters of crankpins in order that they can be machined out. The depth of the deepest cracks should be ascertained before making a request since it is preferable to consider the possible finish diameter rather than quote a minimum diameter. Unfortunately the cracks are often too deep and replacement shafts are required. In the case where the journal is overheated it often leads to distortion of the bedplate in way of the pockets and there are many cases where the bedplate also requires renewal.

Figure 23 on page 14 shows us a typical defect which was prevalent in a particular type of engine a few years ago, some 70% of the engines were affected. In close co-operation with the manufacturers it was eventually brought under control and effectively cured. It took some five years to control and I'm pleased to say that in the last two years there have been no reports of a recurrence. At the present time we have another case where a particular engine is suffering from cracks in the ribs of the cast iron piston crown. Again we have full and close co-operation with the manufacturers with a view to finding and replacing the defective items. Again this could take a period of years since the defect can show itself at any time between new and the completion of the first survey cycle and therefore must be kept under review.

Finally I would like to say that this paper is excellent in its own way dealing as it does with machinery defects only. It would really add to a Surveyor's knowledge and be of great help to him if we could have something similar to this paper on boiler defects and hull defects.

From Mr. F. Kunz:

Mr Munro has presented in admirable brevity, an account of a wide cross section of failures and deserves thanks for compiling such an interesting paper.

The presentation is challenging in that the author's views of the causes of the failures are clearly stated, but rather less emphasis is put on the research which no doubt preceded the formulation of conclusions or the detailed mechanisms by which they occurred. It is hoped that the Society's outport Surveyors were party to these considerations even where details were not advised to head office.

No doubt Surveyors are aware of the need to investigate failures competently, advising owners to use either manufacturers or local expertise or the Society's back up departments where causes are obscure or conflicting interest paralyse effective investigations.

The paper refers specifically to fatigue in a number of cases but it is not unreasonable to deduce from the photographs that fluctuating stresses were responsible for crack propagation in some of the other cases. Failures due to single overloads are quite rare in marine machinery and would lead to considerable deformation of the components in most cases.

Fatigue failures, however initiated, give rise to smooth fracture faces, which are often distinguished by tell-tale beach marks radiating from the start. The failed components are not visibly deformed outside a smaller and rougher final rupture area, but there could be superimposed bruising due to consequential damage, particularly in cases of reciprocating machinery failures.

Effective reporting of failures to ensure that the Society and the marine industry at large can derive the maximum benefit is a very difficult task which is unlikely to be achieved by ticking boxes on a form and Mr. Munro's views as to how this is to be achieved would be appreciated.

From Mr. R. B. Siggers:

Mr. Munro has put into this paper a concise series of most interesting machinery failures along with some causes and cautionary comments.

As a Surveyor involved with plan approval and design appraisal I hurriedly went through the paper to see if more vigilance was required in plan review. On the whole, I found that in so far as the number of plans the Rules require to be submitted is concerned, we could relax.

This paper then, raises some interesting avenues for speculation:

Does it imply that our Rules are well enforced?

Does it perhaps mean that our Rules are out of date and tend to concentrate on items which are today designed to a standard of good reliability?

Does it mean we don't have enough Rules?

Or does it mean that the Rules are satisfactory but failures are caused by, say, operational errors?

The IMO Secretary General, a few years ago quoted that 80% of Marine casualties were due to human error. In this context, Mr. Munro's paper describes mostly a series of failures caused, in my opinion, by inadequate supervision in the operation, surveillance and repair of machinery.

This is possibly the result of centralised control of machinery being specified so frequently, associated with a lack of money spent on crew training and preventive maintenance. Occasionally, as in 4.9 and 4.10, failures are because of design weakness.

It must have been difficult to decide which cases to include and which to leave out when writing the paper, as our Noteworthy Defects List is full of machinery failures. In this context, Mr. Munro's paper and the N. D. L. serve a most important function.

The Society's need to recruit staff to replace the large number of men who are retiring in the next few years will require men with more knowledge and training than ever before, particularly for those men who join the staff without an apprenticeship or seagoing experience. The paper, along with the N. D. L. are admirable sources of data to help bridge the gap between being a new graduate and being an experienced Lloyd's Surveyor.

Regarding the failures in the paper, the fatalities as a result of 4.1—crankcase explosion on page 5, I found very disturbing as it seems that four people died as a result of miscalculation. Does Mr. Munro know the basic cause of the thrust failure?

I am refraining from describing failure cases in which I have been involved as an outside Surveyor. The ones which spring to mind are in the N. D. L. already, whilst others are better described by the Surveyors in Classification Department who get to know more of the story.

Thank you for a most interesting paper.

From Mr. A. A. Wright:

In view of the Society's newly introduced Fuel Oil Bunker Analysis and Advisory Service could you give details of some marine machinery failures which have been caused by unsatisfactory fuel oils and which may have been avoided by a detailed knowledge of the fuel being used.

WRITTEN DISCUSSION

From Mr. P. J. Beaman

The reference, in Section 9 "Flooding", to the importance of maintaining sea valves in efficient condition should also include the importance of ascertaining that valves are correctly reassembled after overhaul.

The writer recalls the case of a general cargo ship, fully laden with an exceptionally valuable cargo, partly refrigerated, which suffered engine room flooding almost to the upper deck and was fortunately saved from sinking by touching bottom at the critical moment.

The vessel was propelled by steam turbines, and after passing the Suez Canal on a northbound voyage it was suspected that the main condenser had become fouled. At the next port of call (where the writer was resident) the Chief Engineer instructed the night watch engineer to close the main sea suction and overboard discharge valves and to open the main condenser inspection doors in preparation for an examination next day.

The condenser lower inspection doors were just below the lower platform although they were accessible from this platform. Unfortunately, after apparently satisfying himself that the suction and discharge valves were closed, the watch engineer commenced opening a lower inspection door. In the process he dropped all the nuts and when he loosened the door the rush of water from the condenser knocked the door onto the tank top. The explanation of this method of door removal, instead of leaving the usual couple of nuts on the threads was that having closed the sea valves there was only the water in the condenser and overboard pipe to run out. When the engine room tank top became flooded as high as the bottom of the condenser the watch engineer realised something was amiss and alerted the Chief Engineer, the other engineers not being available.

The main condenser overboard discharge valve was a gate valve, of very large proportions, fitted in the inverted position and was located close to the deckhead under the lower flat of the engine room. For operation of the valve hand wheel it was necessary to mount a small platform via a short ladder.

Presumably being satisfied that the main sea suction valve was closed the Chief Engineer turned his attention to the Main over-board valve but when he attempted to turn the hand wheel he soon realised that the "open" or "closed" indicator nut on the valve spindle had become locked and was restricting valve spindle movement.

Despite all efforts with a variety of tools the attempts of the two engineers to free the valve were unsuccessful.

In the meantime as the flooding progressed they stopped the running generator which added to their difficulties by having to work by torchlight. When the flood water level was over their small platform they had to abandon the attempt to free the valve and had to swim out from under the deck head.

The progressive flood cooled the steam turbines and the main boilers which had only been shut down a short time previously and also cooled the donkey boiler after the flood water had extinguished its fire. The ensuing damage was extensive and the repairs, which were costly, took nearly a month to complete, although by various early efforts the refrigerated cargo was kept cool, and the main cargo saved, and all was retained on board.

The considered cause was that, after the valve was overhauled at the previous drydocking, the "open" or "closed" indicator nut had apparently been reassembled incorrectly and had not been noticed thereafter which proved to be an expensive oversight. Good fortune had it that the vessel was in port.

From Mr. C. H. Shaw

Mr. Munro is to be congratulated on committing to paper a wealth of practical experience which will be of great value to the field Surveyor.

He raised the issue of worn chrome steel liners by grooving at the liner/sealing ring interface in oil filled stern gland seals.

Development of sealing rings and liners over the years has seen an increase in durability alternating between the steel liner and the sealing ring to the point where the Viton sealing ring with fabric reinforcement down to the sealing edge can have a hack-saw effect on the hard chrome steel liner.

An owner with a ship in dry-dock and a seal unit to renovate would consider the following alternatives:

1. A grooved liner can be machined down to eliminate grooving up to the manufacturer's recommended minimum diameter beyond which the sealing rings cannot reliably take up "the slack". He is not likely to get two such machinings out of a liner.
2. Manufacturers can produce and fit a double spigoted packing piece to bolt behind the stationary seal housing, such that concentricity is maintained and sealing rings run on the unworn part of the liner. Axial shaft movement, however, caused by vibration/going astern/etc. can be significant and care is necessary to ensure that the seals cannot drop back into a groove at maximum for'd or aft shaft displacement. Also an adequate mechanical clearance must be retained between rotating and stationary components in an axial direction.
3. Preferable to 2 therefore is replacement of the worn liner.

Another possible cause of grooving is galvanic pitting occurring, not at the seal/liner interface, but about an inch behind that point where the casing provides elbow support to the sealing ring and radial clearance is reduced. Misinterpretation of galvanic pitting for mechanical wear when fitting the packing piece described in 2 could result in the sealing ring bedding neatly into one of the grooves, the very effect which the owner was aiming to avoid.

With the on-going development of harder liners by ceramic-type coating, the fabric reinforcement in the sealing ring assisting in lubrication and seal unit life generally extending, does Mr. Munro foresee the day when a 10 year survey cycle could reasonably be applied to the tail shaft?

AUTHOR'S REPLY

To Mr. Rennie:

Most of the cases in the paper were brought out from reports of Surveyors in the outports. The cases used were a selection from many similar instances, and if they have one common feature it is the difficulty experienced by the Surveyors in ascertaining the root cause of failure, and certainly in setting it down in the reports.

The Surveyors are enjoined to refrain from including their personal opinions in their reports and as a result, and also by delicate situations which may confront them in the presence of other interested parties, they may feel inhibited.

All this is extremely frustrating to the Technical Records Department, and it would be a great help if the Surveyors would write in confidence direct to TRO on such matters, as the greatest importance is placed upon the collection of reliable data and causes of failures.

It is more than possible that the vibratory stresses were high in the row of turbine blades shown in Fig. 2 for the reason postulated by Mr. Rennie, and it is interesting to speculate that had the steam-excited mode of vibration been designed out, the notches in the tenons caused by the sharp corners in the shrouding holes would not have resulted in failure.

Unfortunately, as in so many cases, the investigation was not pursued to its ultimate conclusion, but the cure was found by removing the stress concentrations.

Case 4.2 is presented in the paper on its facts, and the message about the dangers of performing weld repairs on steel castings for crankshafts, especially in prohibited zones, is of the utmost importance.

The cause of the increase in stress levels to result in the failure was not reported, but it seems likely to have been loss of proper alignment of the crankshaft in its main bearings.

To Mr. Leach:

The third paragraph of the Introduction to the paper made particular reference to the fact that while the effects of stress concentrations have been understood by engineers for many years, serious breakdowns continue to occur today because of neglect of this basic principle. The comment should have gone deeper, and I am grateful to Mr. Leach for drawing attention to the Case 6.1 in the paper, the details of which had been made amply clear in a predecessor's paper presented thirty-five years ago.

It is becoming increasingly clear that it is a matter of major importance to pass on to the succeeding generations of engineers, both at sea and those entering the Society's service as Surveyors, the wealth of experience which has been accumulated, and thereby to reduce loss of life and damage to property.

Mr. Leach's fifth paragraph repeats words which can be heard every day in Machinery Reports Department, and the opportunity is taken to acknowledge that an increasing number of our colleagues are sending in first class photographs with their reports, and they are not only thanked but are hereby encouraged to continue the good work and to persuade others to do likewise. This matter is far more important than it may appear. The field Surveyors' response to these joint appeals can have a significant effect upon the Society's future training programmes.

To Mr. Larmont:

Mr. Larmont is thanked for his further appeal for photographs to be sent in with survey reports. It is clear that Classification Department is presenting a united front in this matter.

Fig. 1 Fatigue fracture of crankshaft

The warning about proposals to effect repairs to cast iron water boxes or heat exchanger covers by padding with plastic compounds should be carefully considered and borne in mind. Failures can result in the ingress of large volumes of water. In UMS ships the bilge water alarms will alert the engineers to the danger. In other ships they may not have sufficient warning to avoid disastrous flooding such as described in Case 9.1 on page 27.

When faced with a defect in a component the manufacturer and the Surveyor should consult together to consider the appropriate action; taking into account the service of the component, the nature, size and position of the defect, the nature and magnitude of the stresses in the affected area and the properties of the material.

In some cases weld repairs are expressly prohibited as in Case 4.2 on page 6, but blending by smooth grinding should always be considered as described in Case 7.1 on page 21, because by this means the stress concentrations which lead to disastrous results can be avoided.

In nearly every case, bearing failure of medium speed engines has been due to a loss of lubrication for one reason or another. In one case indeed, the prime cause was sabotage taking the form of plugging the crankshaft oil hole with a metal bar, and the final result was a classic fracture of the crankshaft. Fig. 1.

The experience of the Crawley Laboratory is that craze cracking is usually shallow and possible to be ground out. However, thermal shock cracks, often longitudinal, are deep and may extend throughout the hardened layer. Renewal is the only solution.

Mr Larmont's penultimate paragraph highlights the excellent relationship which has been developed and nurtured between the Society and manufacturers over the years, which has resulted in the issue of a "SERVICE BULLETIN" to operators from designers, as and when necessary, achieving the desired result with the minimum disturbance to all concerned.

Mr. Larmont is hereby cordially invited to prepare the companion paper on boiler defects for which, he so rightly says, there is a need. He is well qualified to undertake this task.

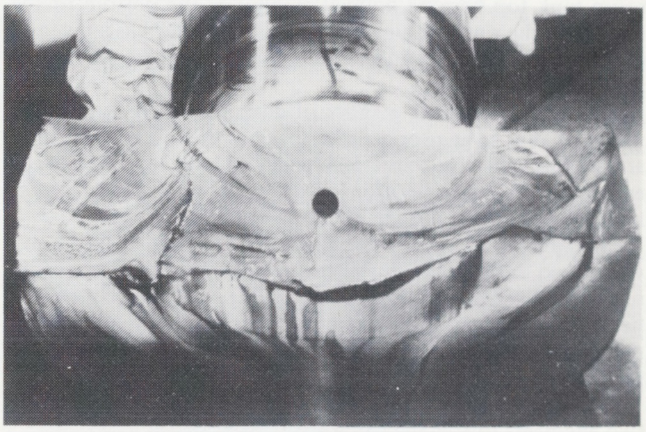

Fig. 2 Fatigue fracture showing beach marks

To Mr. Kunz:

The presentation of the paper was carefully considered. From the outset it was realised that it would be valuable to collect a number of interesting cases of failures and without attempting to set out full clinical analyses, which in any case would be almost impossible because of time delay, to show what went wrong and to highlight the lessons to be learned.

It is felt that this aim has been achieved, and the reply to Mr. Rennie is relevant to the remarks in the opening paragraphs of the contribution by Mr. Kunz.

In Reports Department we are aware of the need to keep the Outport Surveyors informed of what is going on but we also know that there may be cases in which, due to the quite exceptional pressures under which we sometimes find ourselves, we have failed to pass back information. This is one of the reasons for having prepared the paper.

Fig. 2 which shows the fracture face of a large marine engine crankpin is an excellent example of the conchoidal (beach) marks which characterize fatigue failures. The origin was a corrosion pit in the fillet radius, most likely aggravated by misalignment.

In recent months much discussion has taken place on the means whereby Surveyors in the fast-approaching future are to send reports of failures to Headquarters. It is generally understood that such information is of the utmost importance to the Society in order that reliable statistics may continue to be compiled.

The "ticks in boxes" system, which found support in some minds, has been rejected in favour of continuing to ask the Surveyors to describe cases in their own words while bearing in mind that clear sketches and photographs can be of great assistance in reducing the amount of narrative required.

To Mr. Siggers:

Mr. Sigger's reaction to the paper is understandable having regard to his position viz-a-viz the Rules, and I am pleased he finds himself able to relax. This should give him more time to concentrate upon the curious cases which reach him through Machinery Reports Department as feed-back.

He would be a bold man who would positively assess blame for the mass of failures which come to our attention. They may be allocated under the following headings:

(i) *Operational failure*

This can be sub-divided into

1. Crew negligence (carelessness) and
2. Crew ignorance (insufficient training)

The quality, capability and training of the man are of the utmost importance and provided they become consistently of a sufficiently high level failures due to crew negligence can be expected to reduce dramatically.

(ii) *Design fault*

The paper quotes cases of stress concentrations which were built into the design and, in the presence of fluctuating stresses, resulted in serious and costly failures.

All engineers must be aware, or made aware of this danger and understand that—in simplest terms—sharp corners are to be avoided.

Fig. 3

It is hoped that Fig. 3, which shows a medieval chapel high in the Val d' Anniviers in Switzerland will serve to remind readers that the old priest of the chapel found so many defects arising on the sharp corner of his building due to the passage of wheeled vehicles that he washed the corner smoothly away. That man would have been good Surveyor material today!

(iii) *Latent defect in Material*

It is the experience of the Surveyors at the Crawley Laboratory, that from the cases subjected to their investigation failures are most frequently attributable to operational problems followed by design/manufacturing defects. It is most unusual to find a metallurgical defect responsible for failure. Infrequently, defects are found originating from the final stages of manufacturing. (e.g. thermal cracking).

Marine engineers of my generation employed all their senses while on watch in the engine room. It may be worth listing these while considering Mr. Siggers' remarks about centralised control of machinery.

The five faculties are:—

SIGHT
HEARING
SMELL
TOUCH
TASTE

This list has been arranged, not as set out in a popular and widely used dictionary, but in accordance with my recollections, and so it will be understood that TASTE comes in as a last resort!

There is no doubt that a major step was taken when machinery at sea was placed under the control and surveillance of instruments.

An entirely new philosophy was introduced based upon confidence in the reliability of the machines, and in the instruments watching over them.

The change was gradual and was accompanied by, and largely stimulated by, pressure to reduce manning scales.

Experience has shown that marine machinery installations can be and indeed are being operated efficiently in the unmanned mode to the satisfaction of shipowners, classification societys, and the relevant government departments, and no human being sees, hears, smells, touches or tastes anything.

The question of recruitment raised by Mr. Siggers shows awareness of a problem facing the Chief Surveyors and he should be assured that earnest measures are being adopted to cope with the training needs of aspirants to his job and mine.

The engineers concerned with the crankcase explosions described on page 5 of the paper failed to find that the white metal had melted out of the thrust pads.

Many motor ships have been arranged with a separate supply of lubricating oil passing through independent strainers to integral thrusts. It is possible that the strainer became blocked with detritus and the associated alarm did not function either through a fault, or interference because it was creating a disturbance. The inevitable effect would have been serious local overheating with the result as illustrated in the paper.

To Mr. A. A. Wright

Some of the most interesting cases of damage to machinery resulting from the use of unsatisfactory fuels are likely to involve litigation and therefore cannot be discussed here.

There are two case histories which may be of interest. These sister ships entered the same regular service early in 1979 and both suffered similar problems which were eventually traced by the Owners to the presence of catalytic fines in the fuel.

The following are extracts from the Surveyors' reports. It is interesting to note that in all but one case the Surveyors have confined their reports to statements of fact. The exception stated the failure to start the engine was a consequence of bad fuel oil used. Clearly this comment should have been qualified by the words "stated to have been ....", (See reply to Mr. Rennie) and a separate letter sent to Technical Records describing the circumstances.

Case 1. date of build 1–79

date of report 18.4.80

Fuel pump seized with consequent damage to components of pump drive. All affected parts renewed.

date of report 24.1.81

One main engine fuel pump renewed on account of severe wear and one spare pump placed on board.

date of report 6.11.82

Ship entered port of refuge reporting loss of pressure in the fuel manifold. Following testing of individual fuel pumps it was found that one pump was by-passing excessive amounts of fuel due to severe wear of the plunger barrel.

Pump replaced.

date of report 14.11.82

Main engine failed to start while manoeuvring to enter port as a consequence of bad fuel oil used during passage from previous port. One piston was found to have ring grooves severely worn and the piston was renewed. The rings of all other pistons found worn and broken. All renewed.

Case 2. date of build 5–79

date of report 10.9.80

Difficulty experienced when trying to start the main engine on high viscosity fuel although the recommended temperatures and pressures were maintained. The fault became noticeable after the ship was a few months old and had become worse as time went on reaching a point at which if the engine was stopped longer than seven minutes it would not restart, resulting in the fuel system having to be purged and changed over to marine diesel oil.

All piston rings were renewed and one cylinder liner was replaced, all on account of wear, and having thus restored the compression the engine operated normally on high viscosity fuel.

To Mr. Beaman:

Mr. Beaman has told a cautionary tale, and I am grateful to him for it, and also for the homily in his first paragraph.

That reminded me of a survey in drydock in the early 1950's of a weather ship which had been a corvette in the Royal Navy. When the sea valves were opened up it was found that the emergency bilge valve, (sometimes known as the bilge injection valve), the largest bilge valve in the engine room, was a screw-lift valve.

This was required in Naval practice under their pumping and flooding arrangements but is of course contrary to the Society's Rules which require all bilge valves to be of the non-return type.

Mention of this case may serve to remind younger colleagues not to accept matters on their face value. Just because something exists does not necessarily mean that it is right.

The fourth paragraph of Mr. Beaman's story contains the kernel. It is a matter of record that many engine rooms would not have been flooded and many engineers would not have been severely scalded had the men concerned taken the precaution of keeping at least one nut down on the stud for *gradual* easing when joints are to be broken.

Colleagues will perform a service to the industry by talking about such matters with ship's engineers when the opportunity arises. This relates very closely to the theme of the INTRODUCTION to the paper.

To Mr. Shaw:

Mr. Shaw's contribution draws attention to pages 22 and 23 of the paper. The illustrations on these pages show details of one particular manufacturer's product. There are others. However, the type illustrated is frequently encountered.

The latest development permits the chromium steel liner to be renewed together with the sealing rings without removing the propeller from the tailshaft because all the components are in halves, except the sealing rings which are formed as a complete circle with one cut, to be vulcanised.

In a recent discussion with Owners' technical representatives it was learned that the double-spigoted-packing piece referred to by Mr. Shaw is incorporated in the original supply and can be removed as and when required when wear is found on the sleeve, thereby avoiding delay when the ship is in drydock.

My reply to Mr. Shaw's final question is that a 10 year interval between withdrawal of tailshafts for survey is already envisaged.

The shafts concerned will be keyless and at five years a meaningful survey will be required in drydock in order to ensure that there has been no penetration of sea water to the top of the cone where stress/corrosion cracking would be expected to take place. This matter is at present under active consideration by the Society and the National Authorities.

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RELIABILITY AND SAFETY ASSESSMENT METHODS FOR SHIPS AND OTHER INSTALLATIONS

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RELIABILITY AND SAFETY ASSESSMENT METHODS FOR SHIPS AND OTHER INSTALLATIONS

by

D. S. Aldwinckle and R. V. Pomeroy

SYNOPSIS

The paper presents a background to the development of reliability methods and prediction of the probability of failure. The relevance of these assessment methods in determining the safety of ships, offshore and land-based installations is discussed, especially where the transportation and processing of hazardous cargoes are involved.

Some of the theoretical methods are presented, and those methods which have been used within the Society are discussed in detail and illustrated by examples, namely fault tree analysis and failure mode and effect analysis. The identification of critical parts of designs and their operation and their effects upon safety are covered. Methods for assessing the availability and simulating the operational performance of ships or installations are presented. Certain major studies which have made use of these techniques are discussed with examples.

The paper concludes by discussing briefly the analysis of consequential effects, and some of the approaches used in establishing criteria by which the acceptability of risk can be assessed.

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1. INTRODUCTION

In recent years there has been increasing concern and awareness, amongst governments and the general public, about the growing dimension of accidents and the potential dangers and hazards involved. Technology is becoming more advanced and specialised in the search for efficiency. Ships, offshore structures, industrial plants and other engineering installations are becoming more complex, and highly sophisticated systems are being used for operational control and safety. The appraisal methods required to assess the adequacy of the designs and their operational features, in terms of safety and fitness for purpose, also tend to become necessarily specialised and involved.

The Classification Societies have developed comprehensive sets of Rules, Regulations and Codes of Practice based upon good shipbuilding and engineering practice with which to control the design, construction and maintenance of ships. Originally these documents were intended for use by the Societies' surveyors but the documents soon became accepted as basic information for the use of the designers. The Rules reflect the requirements for safety and reliability and have been tailored to meet the needs of specialised vessels such as liquefied gas ships, chemical ships and oil tankers as well as the general needs of less sophisticated ships. The Rules, Regulations, Codes of Practice and direct calculation procedures serve the industries well, but the marine industries and the Classification Societies should not become too complacent. Lloyd's Shipping Information Services casualty statistics (1) for oil and chemical tankers suggest that the incident rate of serious casualties continues to increase although at a reduced rate as shown in Fig. 1. A more detailed breakdown of these rates can be seen in Table 1 for each year in the period 1968-1981 for four deadweight ranges. Some of the recent major casualties showing large death tolls over the last four years are given in Table 2 for oil tankers only (2).

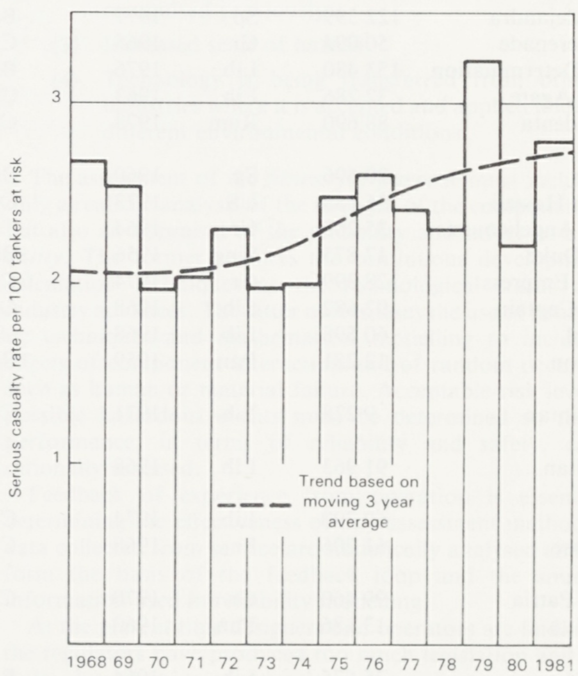

FIG. 1

Serious accidents involving oil and chemical tankers

Table 1 ANALYSIS OF OIL/CHEMICAL TANKER STATISTICS SERIOUS CASUALTIES BY YEAR AND SIZE OF SHIP, 1968—1981 (1)

Year	10,000—24,999 dwt. Serious Casualties	Rate per 100	25,000—44,999 dwt. Serious Casualties	Rate per 100	45,000—149,999 dwt. Serious Casualties	Rate per 100	150,000 dwt. and above Serious Casualties	Rate per 100
1968	47	3·38	17	2·26	15	1·91	0	—
1969	40	3·01	15	1·94	17	2·04	4	7·02
1970	33	2·60	8	1·02	16	1·83	3	2·48
1971	20	1·61	21	2·57	15	1·67	8	4·04
1972	32	2·63	18	2·21	17	1·85	7	2·62
1973	24	2·08	19	2·25	20	2·14	2	0·57
1974	23	2·04	19	2·17	22	2·24	5	1·10
1975	27	2·59	23	2·64	28	2·65	10	1·72
1976	23	2·41	29	3·49	30	2·74	11	1·58
1977	14	1·64	28	3·54	32	2·97	10	1·30
1978	17	2·23	21	2·76	26	2·53	13	1·64
1979	15	2·07	27	3·75	43	4·40	19	2·43
1980	20	2·77	28	2·09	24	2·40	12	1·57
1981	17	2·39	19	2·56	33	3·11	20	2·95
	352	**2·43**	**279**	**2·52**	**338**	**2·50**	**124**	**1·90**

Table 2 MAJOR ACCIDENTS INVOLVING OIL TANKERS 1978—1981 (2)

Ship	grt	Flag	Year built	Cargo	Acc. date	Cause	Deaths
Fotini	40 417	Gr	1964	Repairing at Piræus	Nov 81	Fire	—
Hakuyoh Maru	59 060	Jap	1974	Empty	July 81	Explosion after lightning	7 dead
Anna Xylo	23 760	Gr	1971	Loading crude oil	May 81	Explosion + fire	—
Monticello Victory	28 460	US	1961	Empty	May 81	Explosion	—
Cavo Ceubanos	12 780	Gr	1956	Naptha	March 81	Explosion + fire	5 missing
Blossom	11 834	Lib	1958	Ballast	Dec 80	Explosion	1 missing
Kapetan Markos N.L.	39 169	Gr	1962	Crude	Oct 80	Explosion	1 dead
Oceanic Grandeur	30 714	Lib	1965	Crude	Oct 80	Explosion	2 dead
Campeon	14 863	Sp	1979	Loading gasoline, jet fuel	Aug 80	Explosion	2d 1m
Energy Concentration	98 894	Lib	1970	Discharging crude & fuel oil	July 80	Broke back	—
Mycene	109 992	Lib	1976	Ballast	April 80	Explosion + fire	1 dead
Albahaa B	109 465	Lib	1971	Ballast	April 80	Explosion	6 dead
Maria Alejandra	122 599	Sp	1977	Ballast	Mar 80	Explosion	7d 29m
Irenes Serenade	50 094	Gr	1965	Crude	Feb 80	Explosion + fire	2 dead
Energy Determination	153 480	Lib	1976	Ballast	Dec 79	Explosion + fire	1 missing
Burmah Agate	32 286	Lib	1963	Crude	Nov 79	Fire after collision	16d 16m
Independenta	88 690	Rum	1978	Crude	Nov 79	Explosion + fire after collision	14d 28m
Talavera	20 696	Sp	1960	Ballast	Oct 79	Explosion + fire	1 missing
Chevron Hawaii	35 588	US	1973	Oil	Sept 79	Explosion after lightning	3 dead
Ioannis Angelicoussis	35 269	Gr	1964	Crude	Aug 79	Explosion + fire	4 dead
Cherry Duke	17 875	Sing	1956	Ballast	Aug 79	Sank after explosion	1d 4m
Atlantic Empress	128 399	Gr	1974	Crude	July 79	Fire after collision	3d 26m
Aegean Captain	92 682	Lib	1968	Oil	July 79	Fire after collision	—
Al Wasel	60 598	Lib	1968	Under conversion	June 79	Explosion + fire	3 dead
Mariheron	12 281	Pan	1959	Ballast	June 79	Explosion + fire after collision	—
Bruce Bintan	9 228	Lib	1971	Crude	June 79	Explosion + fire after collision	—
Atlas Titan	91 963	Lib	1968	—	May 79	Explosion + fire while tank cleaning	1d 4m
Seatiger	60 790	Lib	1974	Crude	April 79	Lightning + explosion	1d 1m
Betelgeuse	61 706	Fr	1968	Crude	Jan 79	Explosion while unloading	50 dead
Andros Patria	99 460	Gr	1970	Crude	Dec 78	Explosion + fire	30 dead
Peoso Sun	13 186	Pan	1960	—	Nov 78	Sank after severe explosion	13d 17m
Spyros	35 676	Lib	1964	Repair	Oct 78	Explosion	76 dead
Aegis President	20 073	Gr	1963	Repair	May 78	Explosion	2 dead
Cassiopeia	16 400	Gr	1973	Ballast	Feb 78	Explosion	5 missing

In other industries, such as nuclear power, petrochemical, offshore and onshore oil and gas recovery, Codes of Practice have been formulated on the basis of experience and have been developed over the years in a similar manner to those for ships. However, the treatment of novel features or complex systems is generally beyond the scope of the appraisal methods dictated by these codes; it is necessary to ensure that appraisal methods identify within these designs, and their intended operation, the high risk areas.

Under the prevailing circumstances, it is becoming increasingly necessary to make use of more rational techniques which permit quantification of safety, reliability, risk and consequence of failure (3,4). In order to retain its position of eminence the Society must keep in the forefront of these development trends. By using a rational approach based on reliability techniques, safety assessments can be made for any project at the concept stage, the design stage and at the commissioning and operational stage.

The authors do not wish to suggest that these techniques should replace the well-proven methods used in marine and land industries for safety assurance but that reliability techniques should be used as an enhancement where circumstances dictate.

This paper is intended to introduce some of the techniques currently available for assessing the safety and reliability of ships and other installations. These techniques can be applied directly in the Society's work of safety assurance and used to assist designers and operators in analysing the effects of failure on safety and operability.

2. THE RELEVANCE OF RELIABILITY AND RISK ANALYSES

A modern merchant ship, offshore installation or industrial plant, consists of many components; structural, machinery and equipment. The safety and reliability in service depends on these components functioning in their prescribed modes in a co-ordinated and integrated manner. In critical areas the failure of a single, small item can result in the inability to perform satisfactorily and in certain cases bring about total failure.

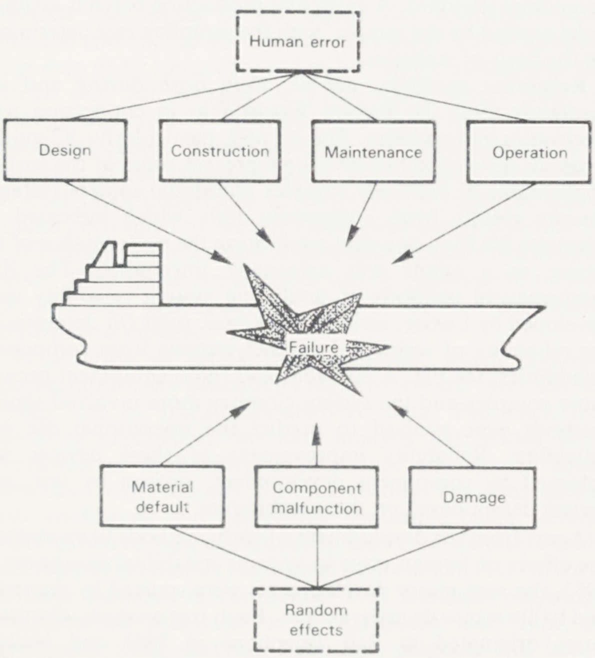

FIG. 2

Human error affecting failure

It is, however, apparent that the provision of the hardware consistent with the requirements for safety and reliability is not, by itself, sufficient; safety also depends on the operational procedures. Many facets of the design, construction, operation and maintenance are heavily influenced by human factors. Human error could result in a failure of equal consequence to the malfunction of a component as shown in Fig. 2. In the effort to increase reliability and safety, human error must be minimized and this is the responsibility of everyone involved in industrial safety.

In the assessment of capability, consideration must be given to all these factors. In particular, the procedure by which the *fitness for purpose* is assessed must make allowances where possible for the combined effects of human error and mechanical failure on reliability and safety.

Reliability is a prerequisite for safety; without reliability there will be no safety. It follows, therefore, that the fundamentals of reliability engineering must be properly understood and applied in order to be able to quantify the expected frequency at which certain undesirable events might occur. For this reason the concepts of reliability, risk analysis and safety assessment are linked together in this paper. Moreover, the concepts of reliability are important in bringing together the three consequential components of a project:

(1) Costs

(2) Benefits

(3) Damage

Clearly, when an entirely new project is conceived and required by an operator, such as a new ship type or an installation where there has been no previous experience, a detailed assessment must be made involving rational, in-depth analysis.

There is a responsibility and duty for all those concerned in the development of innovative technology to assess the safety and risks in some logical and rational manner. It is particularly important to have a formal procedure and to give priority to such an assessment when one or more of the following factors are present:

(1) Technological change which possibly renders existing controls obsolete.

(2) Evidence of new hazards or hazards not recognised previously.

(3) Increased scale of hazard.

(4) Technology is being transferred from other industries where it is accepted and applied under different environmental conditions.

The assessment of the *fitness for purpose* must include not only a realistic analysis of the strength of the component parts but also an appraisal of the reliability and safety as a *single entity*. The former requires the continuous development of calculation techniques as the technological status of the industry advances. The latter necessitates the use of probabilistic techniques and mathematical modelling to include the effects of component interaction and of random occurrences such as human or material failure. Acceptable risk levels for possible hazardous events must be determined so that the performance, in terms of reliability and safety, can be rationally assessed.

Feedback of experience from operation is essential in determining the effectiveness of any assessment method. The data collected from service are statistically analysed and these form the basis of the feedback loop and the source of information used in reliability modelling.

At the present time designers and operators are finding that the regulators have produced too much legislation and many Rules. Introduction of more detailed requirements could have the opposite effect to that desired if designers, operators and management are overwhelmed.

The authors consider that reliability and risk analysis when properly applied following the overall guidelines of the regulators must relieve some of this pressure on the industry. These analysis techniques, when applied by the designers to the intended purpose of the project, should clarify the mystique surrounding some Rules and allow the designers to progress their design in a logical and rational manner, demonstrating that they achieve adequate reliability within required risk levels.

A proposed EEC directive provides for product liability (5). Liability exists if a product is defective and its defectiveness causes damage. Under the United Kingdom Health and Safety at Work Act 1974, the Health and Safety Commission (HSC) aims at arranging policies with a view to:

(a) securing the health, safety and welfare of persons at work;

(b) protecting the public against risk to health or safety arising out of or in connection with the activities of persons at work;

(c) controlling the storage or use of explosive, highly flammable or dangerous substances, and generally preventing the unlawful acquisition, possession and use of such substances; and

(d) controlling pollution caused by the emission into the atmosphere, harbours, etc, of noxious or offensive substances.

Clearly, as assurers of safety the Society must support these aims by ensuring in every way possible that designs are reliable and safe to operate.

However, it should not be construed that resources need to be expended in design or in specifying additional equipment to reduce risks where they meet the acceptance criteria. It follows that the highest priority should be given to reducing risks where they are seen, or calculated, to fail to meet these criteria.

The use of the methods outlined above and the continuous advance from a programme of research and development form the basis of the approach advocated by the authors for the realistic and rational assessment of both safety and reliability. It is based on the fundamental concept that decisions on the suitability of ships and other installations, especially those involving hazardous materials, should be made rationally in a quantitative manner. The methods are conducive to universal application on an individual basis and are, therefore, more relevant to specialised, and often unique, projects than more traditional deterministic Rules of general nature.

The remainder of this paper discusses some of the methods available for the assessment of reliability and safety. Certain of the methods are illustrated in more detail in the Appendices.

3. RELIABILITY AND RISK

The terms *reliability* and *risk* have traditionally been used in technology to refer to some unquantified property of a component or system which concerns its ability to perform as required by the operator. Whether or not an item is considered to be reliable is dependent on the duty performed and the qualitative assessment of the operator. Risks have traditionally been assessed as acceptable or otherwise on the basis of intuitive engineering judgement. Since we are now involved in complex systems *with many interacting components* the assessment of reliability and risk must be more formalized and, to permit analysis, quantitative.

For these purposes, reliability is defined as the probability that an item will perform a required function under stated conditions for a stated period of time. By assessing the failure data from operating experience, or tests under psuedo-operating conditions, using statistical techniques the probability of survival or reliability can be quantified. Alternatively, the probability of failure can be determined theoretically (6).

In a similar manner, risk is defined as the probability that a hazard, in terms of a specified level of loss or injury to persons or property, will occur in a specified period of time. The dictionary definition of risk refers merely to the possibility of occurrence.

In general the loss or injury term to which the probability refers is defined in terms of cost, i.e. either in life or money, or both.

Probabilistic definitions for other terms are also used in reliability type studies. Availability is defined as the probability that an item will be capable of meeting the required demand under stated conditions over a stated period of time. This represents a particular variation of the definition of reliability and is of significance when considering the behaviour of items that are required to perform on demand but spend some time on standby, for instance electrical generator sets.

When considering the performance of a ship or an installation over any period, allowance must be made for outage for maintenance, both planned and unplanned. Since the operation of maintenance of any item is not a precise relationship of time then the concept of maintainability is introduced where maintainability is defined as the probability that a particular maintenance function can be carried out in a specified elapsed time.

By defining risk, reliability and other related terms, as probabilities it is possible to use the rules of mathematical statistics in modelling the performance in operation of any complex system.

Quantitative analysis can be conducted using data derived from service, test, mathematical modelling or by deduction from the performance of similar components or construction for which service or test data is available.

4. HISTORICAL DEVELOPMENT OF RELIABILITY METHODS

The use of statistical and probabilistic modelling techniques to define the performance variability of engineering components is not a recent development. It has its roots in the early developments in quality control, where by sampling the output of mass production the product quality is compared with an acceptance standard. A particular production batch is assumed to be typified by the sample, with the sampling rate determined on the basis of statistics.

Reliability methods, per se, were born during and immediately after the Second World War in connection with electronics and rocketry. The V1 and, particularly, V2 guided weapons developed in Germany represent some of the earliest applications of relatively complex automatic control systems. Despite results from component tests which indicated an adequate life for a one-shot application the performance of the device as a whole was extremely unreliable. The first mathematical methods of predicting system reliability were developed by Lusser, including the basic rules for determining the reliability of series and parallel systems from component reliabilities; see Fig. 3. As radar and radio equipment became more complex and the system circuitry more involved similar methods were evolved to predict the operational life and reliability. Reliability improvement of these devices was achieved by component development, proven by test, and system design based on these techniques.

Apart from the development of early methods to encompass the effects of human error in systems reliability assessment in 1952, the next major developments were spurred by the space and ballistic missile programmes. Fault tree analysis, discussed later, originated at Bell Telephone in 1961 and became computerized at Boeing in 1965. Safety studies using reliability methods became the norm in the defence and aerospace industries.

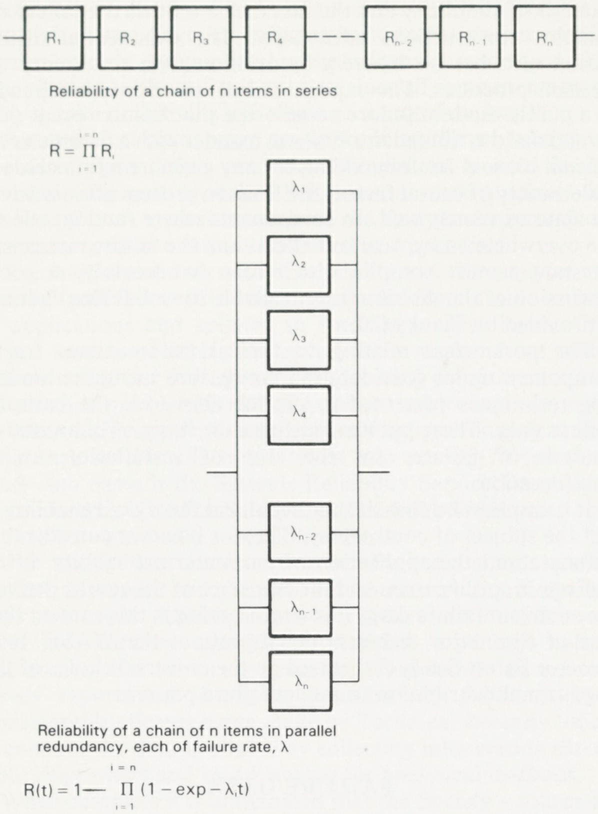

FIG. 3

Series and parallel systems

The early reliability studies, particularly on electronics, made use of failure data obtained by testing a large number of components. As the techniques found more widespread application, so the methods for statistically analysing data from real life experience became more advanced and large communal data bases of reliability data were created, particularly in the nuclear and defence industries.

In the last decade, stimulated by public reaction and health and safety legislation, the use of risk and reliability assessment methods has spread to the higher risk industries—petrochemical and nuclear for instance. The usage is now spreading to an even wider range of applications. Major studies have been carried out, for instance, at Flixborough where fault tree analysis was used to determine the most likely of several postulated causes to have initiated the events leading to the explosion at the chemical plant. The Reactor Safety Study (WASH-1400) undertaken in the U.S.A. (7) and the Canvey Studies performed by the UK Health and Safety Executive (8, 9, 10) resulted from a desire to demonstrate safety to a doubtful public. Both made considerable use of quantitative methods for assessing probability of failure and for determining consequence models.

In addition to safety related studies, which invariably concentrate on low probability high risk events, there has been greater use of statistically-analysed data. Fed back from operating experience, this data analysis has helped in the prediction of availability, maintenance and spares requirements and, more recently, life cycle costing. The techniques are well established and universally applicable being merely a combination of logic and statistics. However, despite considerable interest in reliability in a naval environment (11, 12) the use of these methods in connection with merchant shipping is comparatively restricted. It is anticipated that ships, and specifically those carrying hazardous cargoes, will become more dependent on complex systems of integrated components and such methods of analysis will not only be more relevant but will become a necessary part of both design and operation.

5. RELIABILITY AND PROBABILITY

The intention of reliability and risk assessment methods, as described above, is to model the performance of one or more components in probabilistic terms to enable the likelihood of failure during the required life to be ascertained. The fundamental mathematical theory, presented below, is relatively straightforward. However in many cases very complex statistical mathematics is inevitably used and it would be inappropriate to detail this in a paper of a general nature. The authors consider it sufficient to refer to standard works by Barlow and Proschan (13, 14), Mann, Schafer and Singpurwalla (15), Henley and Kumamoto (16), Green and Bourne (17) and BS 5760 (18).

The basic information required in reliability or risk studies relates to failures and specifically to time to failure. It is worth observing at this point that there is a fundamental distinction between items which can be repaired and those that are non-repairable. In the latter case the only relevant data refer to the time to first failure whereas in repairable items additional information is required on time to subsequent failures.

For any items, which may be a basic component or a system consisting of several components, failure may occur at any time greater than zero and so the distribution of failure times is continuous. It can be described by the probability density function, $f(t)$ or by the cumulative distribution function, $F(t)$. The probability that the item will fail during the time interval between t and $(t + \delta t)$ is given by $f(t)\,\delta t$ and the probability that the item will fail at any time up to t is given by:

$$F(t) = \int_0^t f(t)\,dt \qquad (1)$$

Conversely, the probability that the item will survive until time t is given by the reliability:

$$R(t) = 1 - F(t) \qquad (2)$$

It is expedient to consider a further function, $Z(t)$, which is the hazard function or instantaneous failure rate function, which is defined as:

$$Z(t) = \frac{f(t)}{R(t)} \qquad (3)$$

Since $R(t)$ will always be less than unity it follows that $Z(t)$ will be greater than $f(t)$. By combination of equations (1) and (2) above the relationship between $f(t)$ and $R(t)$ can be shown to be:

$$f(t) = -\frac{dR(t)}{dt} \qquad (4)$$

and hence from combination of equations (3) and (4):

$$Z(t) = -\frac{dR(t)}{dt}\,\frac{1}{R(t)} = -\frac{d\ln R(t)}{dt}$$

$$\text{Hence:}\quad R(t) = \exp\left(-\int_0^t Z(t)\,d(t)\right) \qquad (5)$$

In the simplest case the age of an item has no effect on the failure rate. The instantaneous failure rate is therefore constant for all values of $t > o$ and, conventionally, $Z(t) = \lambda$.
In this case:

$$R(t) = \exp(-\lambda t),$$

$$\text{and } f(t) = \frac{dF(t)}{dt} = \frac{d(1 - R(t))}{dt}$$

$$= \lambda \exp(-\lambda t) \text{ (see Fig. 4).}$$

This is the probability density function of the exponential distribution. If it is demonstrated using statistical goodness of fit tests that the data relating to the item under consideration is satisfactorily modelled by an exponential distribution then the mean time to failure can be shown to be equal to the inverse of the failure rate, i.e.

$$MTTF = \frac{1}{\lambda}$$

In practice most components deteriorate with age and so a constant failure rate is not a good representation. However, it has been demonstrated that the failures of complex items with many components can be satisfactorily modelled by the exponential distribution and so this simplest of functions does have significant value.

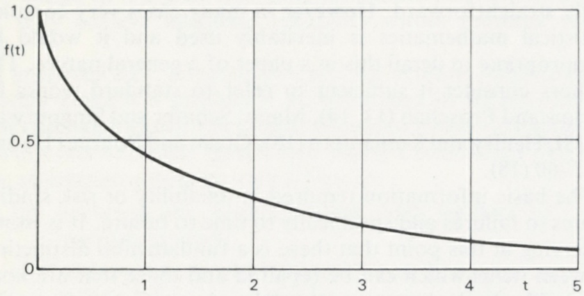

FIG. 4

Unit exponential density function

For engineering items where age does have a significant effect on the instantaneous failure rate there is widespread acceptance of the Weibull distribution (19). The conditional failure rate for the two parameter Weibull model is:—

$$Z(t) = m \lambda t^{(m-1)} \quad \text{(see Fig. 5).}$$

When the shape parameter, m, is equal to unity the Weibull function equates to the exponential distribution with $Z(t) = \lambda$. For values of m greater than unity the instantaneous failure rate increases with time as is the general case for engineering components.

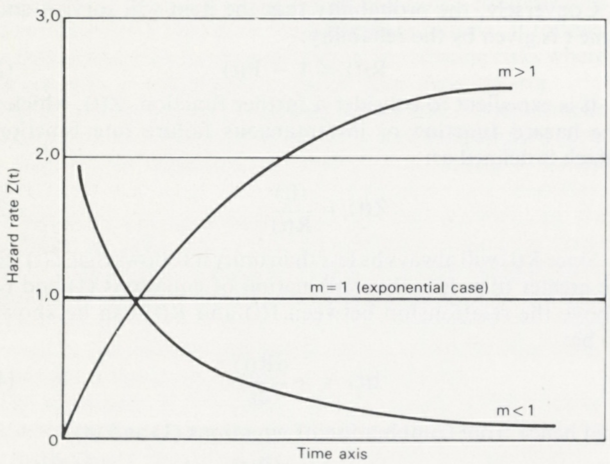

FIG. 5

Conditional failure rate for Weibull distribution

In special cases it may be necessary to model a decreasing failure rate and a value of m less than unity will permit this. The concept of a decreasing failure rate is often not considered to be plausible by engineers. It is however of great significance in terms of computer software, which is becoming of more widespread application with increased automation, since if a failure occurs and is corrected by debugging then the reliability increases.

The variable λ in the Weibull function is the scale parameter. The reliability function, on the basis of equation (5), becomes:

$$R(t) = \exp(-\lambda t^{m})$$

$$\text{and } f(t) = m \lambda t^{m-1} \exp(-\lambda t^{m})$$

Other continuous distributions are used in particular cases; the WASH 1400 reactor safety study (7) was based exclusively on the log-normal model. Other analysts have made great use of the extreme value and gamma distributions. In general the exponential distribution has found greatest acceptance on the grounds of simplicity and the fact that it models the failure of complex constructions adequately. The exponential distribution also has an inherent association with the theory of Poisson processes. The exponential distribution corresponds to a purely random failure pattern and that failures occur due to 'shocks' distributed in a Poisson manner with a parameter λ. Since it is usual for failure data for any given item to include a wide variety of causal factors the Poisson process often models the data extremely well. In components where random effects are overwhelmed by wear out effects and the failure rate is not constant a more complex distribution is necessary. A good discussion of the distributions available for modelling failures is provided by Blanks (20).

The parameters relating to typical failure times for a component under consideration are derived using the modelling techniques presented in outline above on the basis of failure data. These parameters form the basis of quantitative analysis of failures for the ship or installation under consideration.

It is emphasised that the mathematical theory of reliability is not the subject of controversy. There is however considerable debate about the application of particular probability distributions in specific cases and the relevance of the results derived from certain failure data. It is worth noting in this context that one of the major technical debates about the WASH 1400 Reactor Safety Study (7) centred on the universal choice of the log-normal distribution to model failure patterns.

6. FAILURE DATA

Failure data, or more explicitly information relating to the time to first failure or, where relevant, the time between successive failures, are the basis for all quantitative analyses concerning the performance of components or systems. The basic data is analysed using the statistical approach described above and the parameters which represent the performance of the 'typical item' are derived for use in such techniques as fault tree analysis. The quality of the parameters available to the analyst is dependent on the size of the sample, the consistency of the results and the fit of the model.

For any item the information concerning the active life to failure or between failures can be established by one of the following methods:

(1) Feedback from operation, adjusted as appropriate.
(2) Test under service operating condition.
(3) Compressed time testing.
(4) Advanced stress testing.
(5) Probabilistic analysis of design.
(6) Critical appraisal of results for similar items.

In general, component testing in sufficient numbers to generate a statistically meaningful sample is restricted to mass production items such as domestic appliances and electronic components. With the exception of some electrical and electronic items, failure data derived from testing is not generally encountered in the areas of interest to the Society. In any case, testing to the life expected of marine or industrial applications is not usual although the aircraft industry does follow this approach with full scale fatigue testing of primary structure and systems.

The most useful method for deriving the basic parameters for reliability and risk analyses for ships or industrial applications is by consideration of the results of experience or by fundamental analysis. The latter requires the probabilistic analysis of loads, material and structural properties to derive an estimate of reliability (6). This approach is of greatest value where no service experience is available or where failures are rare due to high reliability. By way of example, there are relatively few failures of pressure vessels and hence the

confidence of the resulting failure rate derived from service is not high. There have for instance been no failures in certain types of nuclear components but the failure rate associated with reliability and risk studies is not zero since all components must have a finite probability of failure no matter how small.

An analytical route based on determining the probability of not detecting a defect of critical dimensions is used in the Marshall Group study of the PWR pressure vessel proposed for Sizewell (21). A typical example of the analytical approach to determining failure rates is described in Appendix 1.

The majority of data used in reliability and risk analyses are derived from failure information collected from a wide variety of applications and collated to form large data bases. The largest sources of such data include information from many industries and for most general engineering components. The information produced is also of a general nature and care must be taken in its application to ensure that environmental and other task specific effects are taken into account. Typical of these data bases is the Systems Reliability Service Data Bank maintained by UKAEA Safety and Reliability Directorate and available to users on a subscription basis.

The major data bases are generally maintained by the nuclear, aerospace and chemical industries to suit, principally, their own needs. Although data of a general nature can be of great use, *industry—specific* information is of high value. The Society has for many years collected failure data from survey reports on ships, as described by Sullivan (22). Considerable effort is being made by Technical Records Office to enhance the data available by collecting information direct from shipowners and by advancing the analytical methods.

When complete it is anticipated that the Society's source of failure related information concerning marine applications will be extremely valuable to the marine industries. The work is as yet at an early stage and no doubt will form the basis of a later paper. Examples derived from the TRO database are included, with some comment, in Appendix 2.

In summary it is anticipated that the majority of basic failure rate information required by the analyst will, for marine and industrial applications, be derived from service experience. For the former the Society's Reliability Data Base will form the principal source whilst for the latter resort will be made to more relevant sources of information. Any failure rate information, and particularly that lifted from an unfamiliar source, must be critically analysed to ensure relevance to the specific application. The analysis of the probability of failure for a novel construction of liquefied gas containment based on generic failure data is included in Appendix 3. Most controversy concerning reliability and risk analysis centres on the modelling of failure data to derive the basic parameter and the relevance of general service experience to a specific example. It is authors' contention that, with care, realistic values can be obtained and logical conclusions drawn from the analysis of novel designs using such data.

Table 3 EXAMPLE OF FMEA SHEET

FAILURE MODE AND EFFECT ANALYSIS
TABLE:
SYSTEM:
SUB-SYSTEM:

1. **Component Name:**
2. **Function:**
3. **Mode of operation:**
4. **Failure mode:**
5. **Failure cause:**
6. **Effect of failure on:—**
   - 6.1 **Component/functional assembly**
   - 6.2 **Sub-system**
   - 6.3 **Project**
7. **Failure detection method:**
8. **Corrective action:**

7. FAILURE MODE AND EFFECT ANALYSIS

The key to successful failure analysis lies in the application of basic tools which discipline the analyst to break the design, and its intended operation, into discrete parts. In this way the structural and engineering drawings, if available, as an expansion of the specification can be broken down to significant parts and events which may interact during operation. This is particularly important where there has been no previous experience in the design proposals. Failure Mode and Effect Analysis (FMEA) (23) is one such basic tool which complements another analytical tool known as Fault Tree Analysis (FTA) which is described in the next Section.

Table 4 CHECK LIST OF HAZARDOUS SOURCES

Check list of Hazardous Element Sources	Check list of Hazardous Energy Sources
1. Acceleration	21. Weather and environment
2. Contamination	22. Fuels
3. Corrosion	23. Propellants
4. Chemical dissociation	24. Initiators
5. Shock	25. Explosive charges
(a) electrical	26. Charged electrical capacitors
(b) thermal	27. Storage batteries
(c) inadvertent activation	28. Static electrical charges
(d) power source failure	29. Pressure containers
	30. Spring-loaded devices
(e) electromagnetic radiation	31. Suspension systems
	32. Gas generators
6. Explosion	33. Electrical generators
7. Fire	34. R. F. energy sources
8. Heat and temperature	35. Radioactive energy sources
(a) high temp	
(b) low temp	36. Falling objects
(c) temp variations	37. Catapulted objects
9. Leakage	38. Heating devices
10. Moisture	39. Pumps, blowers, fans
(a) high humidity	40. Rotating machinery
(b) low humidity	41. Actuating devices
11. Oxidation	
12. Pressure	**Check list of Hazardous Operations**
(a) high	
(b) low	
(c) rapid changes	42. Welding and routine maintenance
13. Radiation	
(a) thermal	43. Tank cleaning/inerting/ gas freeing
(b) electromagnetic	
(c) ionizing	44. Extreme environment operations
(d) ultraviolet	
14. Chemical replacement	45. Proof test of major components/sub-systems/systems
15. Shock (mechanical)	
16. Stress concentrations	
17. Stress reversals	46. Cargo loading/transfer/ handling
18. Structural damage or failure	
	47. High energy pressurization/hydrostatic-pneumostatic testing
19. Toxicity	
20. Vibration and noise	
	48. Manœuvring in restricted waters
	49. Berthing operations

The FMEA method is designed to look at the possible failure states of components of a system and to identify all possible consequences within the design during normal, but including abnormal, operation. It is a qualitative analysis and is ideal for identifying the need for detection procedures and corrective measures.

A typical FMEA table is shown in Table 3; it represents a logical approach to safety analysis. A check list of hazardous elements is helpful. An example is given in Table 4. Through engineering judgement, intuition and professional experience together with historical records of similar designs, it is possible to build up a picture of the likely performance through the logical format of the FMEA table.

FMEA is basically a 'bottom-up' method used to perform single random failure analysis. Starting with a postulated failure mode, the possible consequential effects are deduced for certain sets of circumstances. FMEA is helpful in constructing event or fault trees which are sometimes referred to as dependence diagrams.

Some examples of FMEA are included in Appendix 4 in connection with the analysis of a novel offshore LNG liquefaction and storage ship attached to a single point mooring.

8. FAULT TREE ANALYSIS

In novel projects involving complex arrangements of familiar and unfamiliar components and systems, it is important to analyse the possible mechanisms of failure and to perform probabilistic analyses to determine expected rate of failures. A FMEA is rarely adequate in such cases because of the large number of basic events and the complex consequences of failures. Fault tree analysis (FTA) is the technique that has been developed for use in this type of analysis (24, 25).

FTA allows the logical representation of many events that interact to produce other events. It results in the development of a complicated network of inter-related events leading to the top event of interest through simple logic gates. These are mainly AND or OR gates (see Fig. 6). Sometimes dependency

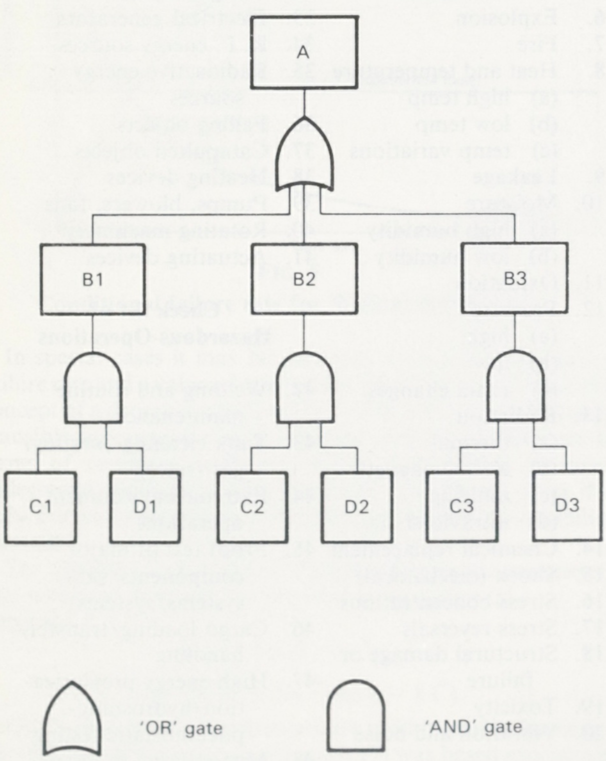

FIG. 6

General representation of a fault tree

or logic diagrams are needed before FTA can commence to help in understanding how the system functions. For simpler systems these diagrams or FMEA are unnecessary and fault tree construction can begin immediately.

The system failure event, or an undesirable event as it is often called, that is to be studied is referred to as the top event. Working downwards the failure event tree structure is created terminating at basic events. These basic events are known as primary faults usually caused by:

(1) structural fault,
(2) failure to open or close, or
(3) failure to start or stop,
(4) an operational error.

Usually all basic events are statistically independent. In some cases the same basic event, such as a fire or a ship collision, may effect several apparently independent components and produce a set of circumstances that inevitably will result in the occurrence of the top event. This type of event is referred to as a common cause failure.

Once a tree has been created for a system, analyses can take two forms, i.e. qualitative analysis and quantitative analysis.

Qualitative analysis of a fault tree reduces the tree into combinations of basic events sufficient to cause the undesirable top event to occur. Each combination is called a 'minimal cut set' or 'implicant set' of failure modes for the tree. The general representation shown in Fig. 6 shows three such minimal cut sets; C1 and D1, C2 and D2, and C3 and D3 which result in the top event A.

Quantitative analysis of a fault tree involves the transformation of its structure into an equivalent probability form and calculating the probability of the undesirable event from the probabilities of occurrences of the basic events. The probability of basic events is the probability of failure of each component or sub-system corresponding to the operating life of interest, calculated in the manner described in Section 5.

The probability of the top event can be determined in two ways:

(1) If minimal cut sets have been already determined, the probabilities of basic events can be combined by a program.

(2) If the size and complexity of the tree is small, the calculation can be performed by hand.

In the former case the combination of probabilities (26) is performed by computer from:—

$$P(A_1 + A_2 + \dots + A_N) =$$

$$\sum_{n=1}^{N} P(A_n) - \sum_{n=1}^{N-1} \sum_{m=n+1}^{N} P(A_n A_m) + \dots$$

$$+ (-1)^{N-1} P(A_1 A_2 \dots A_N) \tag{6}$$

or when the evaluation of occurrences which are independent and highly infrequent from:—

$$P(A_1 + A_2 + \dots A_N) = \sum_{n=1}^{N} P(A_n) \tag{7}$$

In the latter case, usually when all probabilities are less than 0.1, the combination of probabilities can be found from equation 7 and

$$P(A_1 A_2 \dots A_N) = P(A_1) P(A_2) \dots P(A_N) \tag{8}$$

depending upon whether they are AND or OR gates.

The resulting probability is used to calculate the probabilities higher up in the tree until the top event is reached. Where a large tree contains 100 or more basic events, it should be done by computer program for convenience and accuracy. Within the Society a capability exists to evaluate the minimal cut sets using

LR.FTAP (27) and afterwards combining the event probabilities by using LR.FTREP (28). Some practical examples in the application and analysis of fault trees are given in Appendices 4 and 5.

Having obtained the probability of an undesirable event, it is then possible to continue to perform reliability and risk analyses within a safety study. These aspects are now discussed in more detail in the following sections.

9. AVAILABILITY AND SIMULATION

The subject of availability and simulation, including maintenance and repair, can be very involved mathematically. It deserves a presentation in its own right. However, this paper does warrant a very brief introduction to the subject following on from the foregoing and serving as background to the example on a mission simulation investigation for an ice-breaking LNG Carrier, part of which is summarised in the Appendices 5 and 6.

Availability is defined as the proportion of the total time a component, equipment, system, or ship or installation is performing in the desired manner. It therefore must take into account the time taken to repair or renew a component if it affects the overall performance of the ship or installation.

Availability can be defined very simply as:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where MTBF = Mean time between failures
MTTR = Mean time to repair

Clearly, as the availability approaches unity so the ship or installation is performing its function reliably and safely with maximum revenue to the owner.

The simulation of reliability and availability can be performed in a continuous and accelerated time domain. Simulation techniques are very powerful where there has been no previous overall experience of a ship or installation. It is a very useful way of performing sensitivity studies to observe the effect of changes in the Rules and Regulations, design, operation or logistics on the overall performance. In this way availability can be deduced and the revenue for the operator determined from the technical performance.

The speed and dexterity of the digital computer lends itself to such simulation. Provided a logical procedure can be adopted for randomly generating failures some idea of the effects can be calculated.

One way of generating independent failures for each sub-system is by use of a random number sequence. By using a negative exponential cumulative probability function (see Section 5) and the MTBF for each sub-system, the time to failure (TTF) can be found from:

$$\text{TTF} = -\text{MTBF} \ln(\text{RN})$$

where RN = Random number from 0 to 1 generated by the Monte Carlo method.

Failure is assumed to occur if TTF $\leqslant$ computed time from start of appropriate simulation phase.

This approach can be very valuable in looking at failure frequencies and the consequence of failures. As far as risk analysis is concerned these consequences, provided they can be quantified in a suitable way, should be compared with acceptable risk levels. This is now expanded and discussed in the next two Sections.

10. CONSEQUENCE ANALYSIS

The end result of reliability type studies is dependent on the purpose of the study. In some cases reliability analysis is used to compare the anticipated performance, given certain failure parameters, of competing arrangements. The aim of this type of study is to select the optimum arrangement and, hence, the desired result of the analysis is the comparative assessment of the respective system reliabilities. In other cases the results of the analysis are used to predict spares usage, maintenance costing, loss of earnings and other operational costings as discussed in the preceding section. For this type of study it is necessary to assess the consequential effects of failure.

For risk analyses, consequence analysis takes on a very significant role. The aim of the risk analyst is to quantify, in terms of frequency of occurrence and 'cost', all postulated events in order to produce an expected value for the consequence of failure.

It is usual to conduct consequence analysis in two stages. In the first stage a simple scoring technique is applied using an arbitrary scale to represent the analyst's considered opinion of the severity of the consequence of failure. Certain types of failure can be grouped where the consequences will be similar although possibly of different scale. For example in a liquefied natural gas complex all releases of product can be considered to be generally similar, whether from vessels, valves, pipes or storage tanks. Cognizance must be taken of physical location and environmental conditions such as wind speed and direction, temperatures and sea states.

The second stage of consequence analysis involves the probabilistic modelling of the effects of the postulated failure. By its very nature risk analysis is normally concerned with low probability events the occurrence of which could lead to loss of life, widespread damage to property or adverse environmental impact. This type of consequence is of great concern to the general public and health and safety legislations.

The consequence model must include all factors, both constant and variable in nature, that have a bearing on the final end result of the postulated failure and hence details are not presented here. By way of example consider the release of flammable vapour from a petro-chemical complex. A probabilistic model of the size of the fracture and hence the rate of release of vapour is constructed. The behaviour of the vapour after release will depend on the wind speed, direction and turbulence at the time of the accident. For certain patterns the vapour will harmlessly disperse. For other cases a flammable mixture will form in the gas cloud and under prescribed circumstances will ignite. It is usual to consider three categories of gas dispersion:

(1) Plume with a high initial velocity (e.g. fracture of a high pressure pipe such as a gas pipe riser from offshore gas field).

(2) Buoyant plume with zero initial momentum (e.g. sudden failure of non-pressurised containment system leading to release of liquid which flash vaporises).

(3) Dense gas surface release (e.g. boil off from spills of liquid gas).

The mathematical models of each category are reviewed elsewhere (29). In general they are not transferable. However, very little validation of the models has been carried out although recently results of SHELL's offshore LNG and LPG tests have been presented (30). The loss model will depend on the location of the gas cloud on ignition and also on possible knock-on effects, principally further damage to plant in the complex.

The loss model will allow the analyst to determine the likely loss of life or injury within and outside the plant, the damage to property and consequential costs and any resultant pollution for any set of prevailing conditions.

As a second example consider the result of fracture in the gas feed piping which transfers gas via a single point mooring to a floating liquefaction plant. An example of the effect of wind speed variation is shown in Fig. 7. On the assumption that the process ship will weathercock, wind direction is not significant. This prediction, based on the work of Cox (29) allows the determination of the consequences of such a fracture.

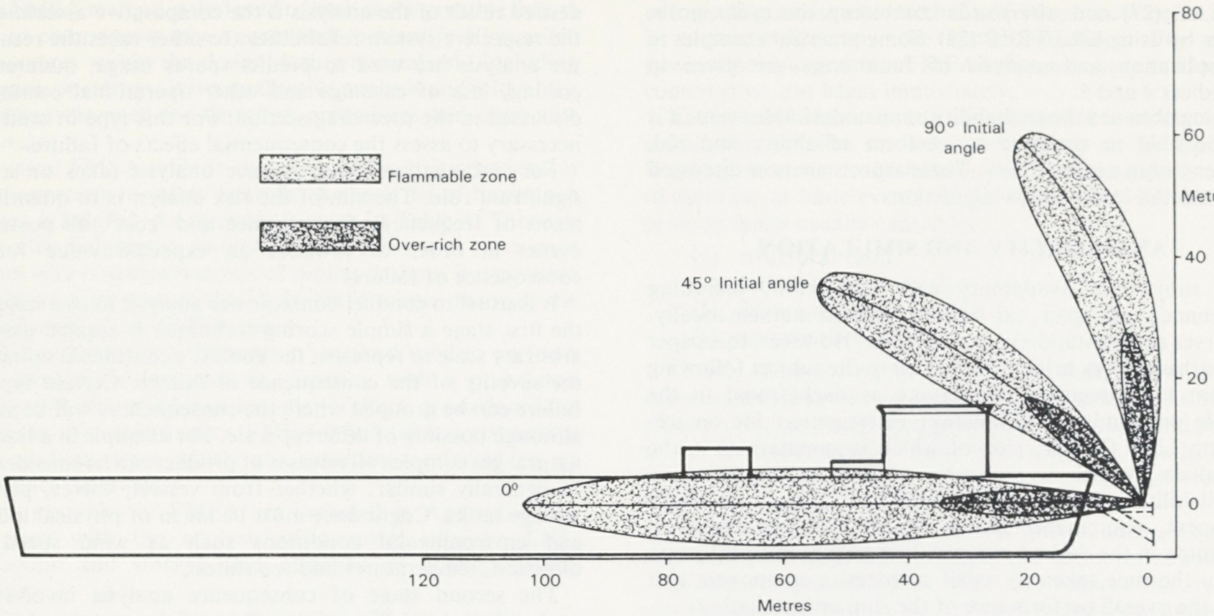

FIG. 7

Full bore release of feed gas from single point mooring (for 10 m/sec windspeed)

The end result of the analysis is a relationship between probability of occurrence in a given period and consequential cost. This represents a summation over all postulated events of the product of the probability of failure and probability of the related event resulting in the specific consequential damage.

$$P_{OC} = \sum_{\text{all events}} (P_E \times P_C)$$

where P_{OC} = the probability that a specified consequential cost will result during a specified time.

P_E = the probability that a specified event will occur during a specified time.

P_C = the probability that the specified event will result in the specified consequential cost.

Many damages to ships result from collision where the consequences depend on the kinetic energies involved. The probabilistic modelling of these effects is used to illustrate this aspect of consequence analysis in Appendix 7.

The model of consequences of accidents and their frequency for the subject under consideration must now be assessed and its acceptability judged on a rational basis.

11. SAFETY AND RISK CRITERIA

Once the foregoing quantities have been derived, the decision on risk acceptability can be based on rational reasoning rather than on subjective judgement. But what are the criteria that determine whether a ship, a plant or an installation is *safe enough* ? By postulating failures and attributing probabilities of occurrence to these failures, it has already been admitted that absolute safety (that is total freedom from failure) is unattainable. Some formula must be derived to say that, whilst agreeing that a postulated failure might occur and that certain consequential damage or loss of life could possibly ensue, the case under review is not unduly hazardous by comparison with other risks.

The admission of possible failure events provokes a reaction in certain groups of the population that leads to the counter statement: 'If it can fail it isn't safe enough'. The maximum consequential damage is assumed with no regard for the likelihood of occurrence. This viewpoint gives rise to the extreme opposite response that is favoured by decision makers: 'Any reasonable person in the same circumstances would take the same course of action'. These decision rules are the so-called 'mini-max rule' and the 'reasonable rule'. Both require no quantification and subjectivity is influenced by the standpoint of the individual concerned.

Most engineering and scientific decisions are made on the basis of calculation, quantification and comparison with known specific values. In the field of safety and risk assessment it is desirable to construct targets and goals by which to assess the acceptability of a project in the same way as the designer compares predicted stress values with material properties. The preceding sections of this paper have discussed methods of predicting the consequences of hazardous events and the frequency of occurrence in a given time interval. How can the analyst decide whether the project is acceptable on the basis of these results? How safe is safe enough?

The debate concerning risk criteria is far from complete but the use of 'expected value' methods is accepted. The Health and Safety Executive in UK is committed to quantification of risks even if precise criteria for judging the results are not available (31). The Canvey study was based on such techniques (8, 9, 10). The nuclear power industry is likewise committed; even in the United States where the WASH-1400 Reactor Safety Study (7) was the subject of adverse comment by, among others, Lewis et al (32) probabilistic risk assessment exercises will have been conducted for 28 reactors by 1983 including many sponsored by the utilities themselves.

The question of risk acceptability for a given project also hinges on the cost-benefit aspects and consideration of alternative methods of achieving the same ends. An interesting discourse on this subject is provided by Kaplan (33) whose argument is sound and logical but lacking in numerical values.

Since in general the type of event which is analysed by these methods results in loss of life the following discussion will concentrate on this aspect and will omit reference to loss of

property or damage to the environment. These latter two forms of consequence are readily analysed in accounting terms and viability can be assessed by a cost-benefit study.

The starting point must be the existing risk of death due to natural causes, motor accidents, fires, aircraft crashes and so on, which is apparently acceptable to the population. The accidental death risk per person per year for Great Britain in 1973 is given in Table 5 from Griffiths and Fryer (34). These are individual risks. Table 6 compares these risks with the overall risk of death and emphasises the relative importance of accidental death and that due to all causes.

The risks predicted for individuals can be compared with these values but cognizance must be taken of factors such as whether the mechanism of the risk is understood or not, whether involvement is voluntary or not and whether death is instantaneous or due to long-term health deterioration.

Table 5 Accidental Death Risk

Type of Accident	Risk/person/year $\times 10^{-6}$
All accidents	345
Road Transport	145
Falls	111
Fires	18
Choking and Suffocation	16
Poisoning	16
Drowning	11
Natural and Environmental	3·6
Air Transport	3·3
Rail Transport	3·1
Water Transport	2·6
Electrocution	2·4
Delayed effects of accidents	2·2
Medical misadventure	1·6
Lightning	0·17

Notes: 1. Risks for Great Britain 1973 derived from Griffiths and Fryer.
2. Total number of accidental deaths in 1973 was 18947.
3. Individual risks based on population of Great Britain.

Table 6 Risk of Death due to accidental and natural causes

Cause of Death	Risk/person/year $\times 10^{-6}$
All causes	
Whole population	12000
Aged 0–4	3440
Aged 5–14	190
Aged 15–24	300
Aged 25–34	480
Aged 35–44	1620
Aged 45–54	5500
Aged 55–64	14770
Aged 65–74	42230
Aged 75–84	107300
Aged 84 +	202350
Cancer	2500
All accidents (see Table 11.1)	345

Notes: 1. Risks for Great Britain 1973 based on population at risk.

Different criteria may need to be applied to the employee at a chemical plant and to the non-employee who lives or works adjacent to the same plant. Lack of individual control over risk generally requires a reduction of the acceptance criteria.

It is generally accepted that individual risks of less than 10^{-6} per year are trivial and that risks of greater than 10^{-5} per year require action to reduce them, as shown in Fig. 8. The area bounded by these limits requires reduction of risk where economically justified on a cost-benefit basis. This approach is supported by both the nuclear (Kinchin, 35) and petrochemical (Kletz, 36) industries.

Individual risks by their very nature are accepted, or not, by decisions by individuals on particular merits. However major events of the type usually subjected to the type of analysis presented above will in most cases affect large numbers of people in multiple fatality accidents. Any assessment criteria for these societal risks must make allowance for the fact that there is essentially no correlation between the general public's perception of a risk and its actual value. This is demonstrated by Slovik and Fischhoff (37).

Farmer (38) introduced the use of log-log plots of the frequency of events, f, causing N or more deaths per year against the number of fatalities, N and a limit line. These so called f – N plots are best illustrated by the figure reproduced from the WASH-1400 Reactor Safety Study (7) as Fig. 9 which compares known risks with the predicted risks due to 100

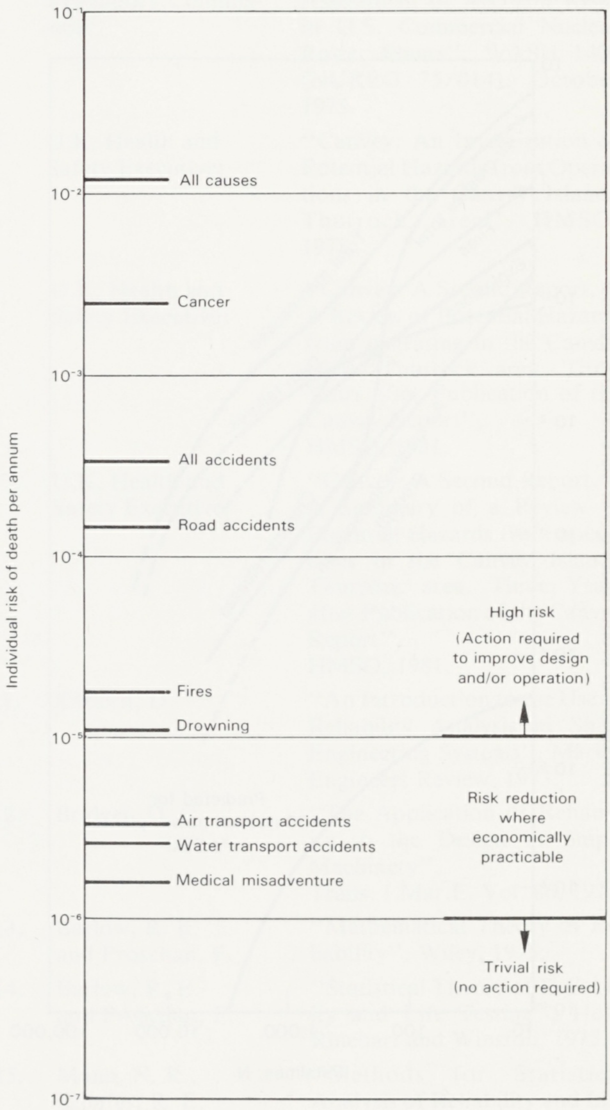

FIG. 8

Individual risks

nuclear power plants in the USA. These curves are specific to the size of population and so care must be exercised in their usage.

From the information collated by Griffiths and Fryer (34) the authors have derived Fig. 10. This is the f – N plot for the frequency and severity of multiple frequency accidents in the United Kingdom. An iso-risk line of fN = 10 is shown which is proposed as the model for such events to which the general public is knowingly submitted and which does not cause apparent adverse reaction. Kinchin (35) has suggested that the aim for hazardous installations should be a risk below the iso-risk line of $fN = 10^{-4}$. Fig. 11 shows the iso-risk lines of fN = 10 and $fN = 10^{-4}$ together with the predicted risk curves for Canvey (8) and the predicted curve by Farmer (39) for 30 nuclear reactors in the United Kingdom. The goal of $fN = 10^{-4}$ is clearly difficult to achieve with current safety engineering practice.

The preceding discussion has outlined the processes for establishing safety and risk criteria on which to judge acceptability of the frequency/consequence relationship derived from the analytical methods presented in previous sections. A guide to numerical values has been included. However, it is important to note that the Norwegian Petroleum Directorate has issued guidance (40) on acceptable safety criteria for offshore installations, i.e. the total probability of occurrence or risk should not exceed 10^{-4} per year for certain main functions.

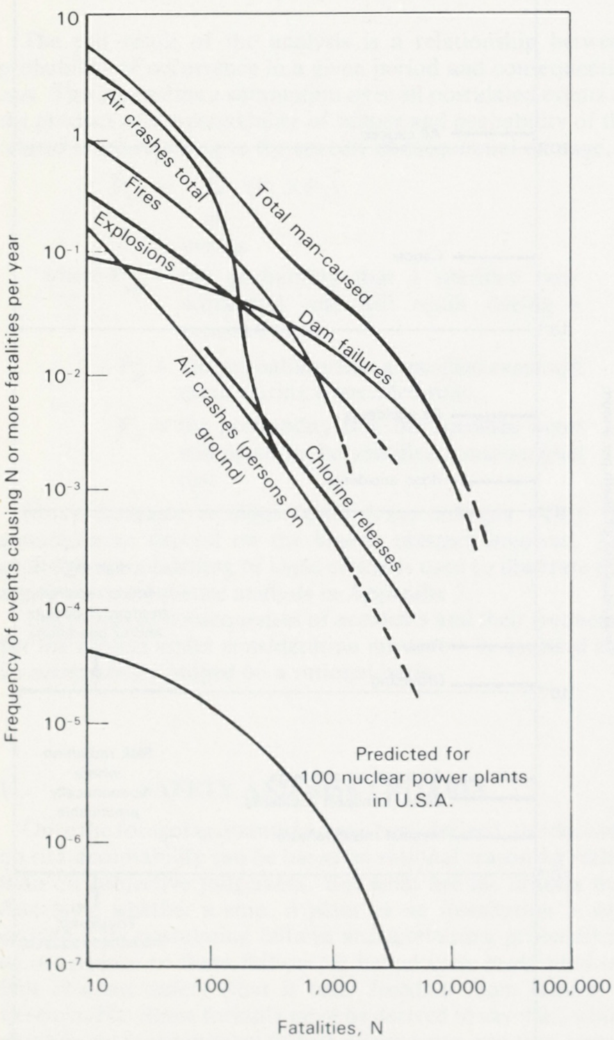

FIG. 9

Comparison of risks for fatalities (7)

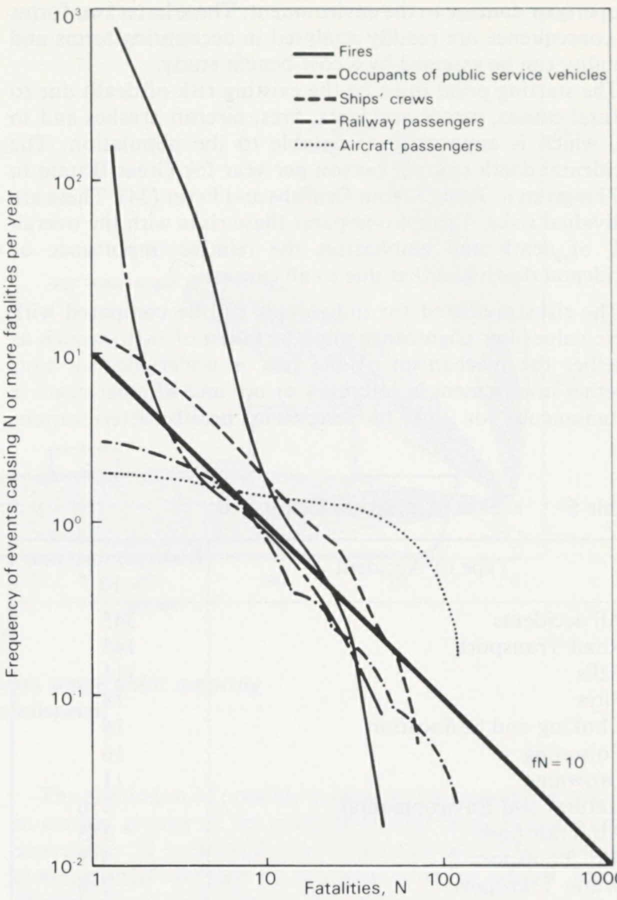

FIG. 10

Frequency of multiple fatal accidents in the U.K. (34)

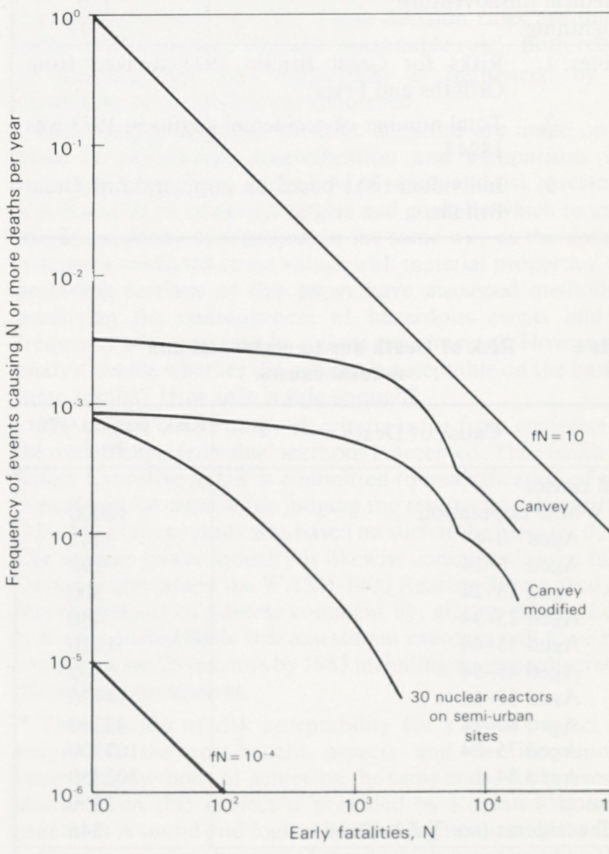

FIG. 11

Plot of event frequencies against early fatalities for the U.K.

In summarising, it is considered that where risks are confined to the ship, installation or plant, individual risks should be compared with existing individual risks and if possible limited to 10^{-5} per person, per year and the multiple fatality events should be below the iso-risk line fN = 10. Where the event affects persons who have no active involvement in the ship, installation or plant then a reduced risk level should be established based on backgound risk levels and factors to make allowance for fear, involuntary involvement and lack of comprehension. It is also necessary, in any assessment of predicted risk against acceptance criteria, to pay full attention to any uncertainties that may have been introduced into the analysis in the failure data or in the consequence analysis.

12. CONCLUDING REMARKS

In this paper the authors have attempted to summarise the fundamentals behind reliability and safety assessment techniques. Some recent examples, although far from complete, give an insight into their application and potential. The application of these techniques is becoming a rapidly developing technology whose usefulness will only grow where there is a need, an understanding and above all a determined effort by the Society to continue to record the technical performance data on the reliability and damage of components in ships and installations. This information must continue to provide the Surveyor with the practical back-up of in-service performance.

However, it has been shown that safety and reliability assessments go well beyond performance data. Much further work needs to be done in the area of application and the establishment of risk criteria. The basic tools are there but more experience and conviction in their use in new areas of technology is necessary.

Safety studies carried out at the right time are without doubt cost-effective in the long run. Without the logical and experienced application of these techniques to innovative projects, which appear with increasing frequency, there may be further mistakes and accidents, some very damaging. The sooner a potential hazard in a design concept or design detail can be identified, and modified or eliminated, the better. For those parts of the design which are identified and accepted, it is then important to ensure that agreed quality control is implemented during manufacture and that they are adequately surveyed in service.

The authors believe that reliability and safety assessment techniques discussed in this paper will have much to offer the Society in the future. Through their continued application a common language should emerge so that communication between industries and regulatory bodies is enhanced. Moreover the benefits to the industries that the Society serves will be considerable.

13. ACKNOWLEDGEMENT

The authors wish to record the initial encouragement from Mr. Marsden, in writing this paper. They acknowledge the assistance and comments of many of their colleagues who have contributed to the material embodied in parts of this paper. Particular thanks are also due to their respective departmental heads, Dr. R. A. Goodman and Mr. D. Rennie.

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15. GLOSSARY OF TERMS

Accident — An event which may cause possible danger to life or damage to plant and which is unpredictable either with regard to its form or to its occurrence in the time domain.

Availability — The ability of an item (under combined aspects of reliability, maintainability and maintenance support) to perform its required function at a stated instant of time or over a stated period of time.

Catastrophic failure — The failure of a component or system in which its particular performance characteristic moves to one or the other of the extreme limits outside the normal specification range.

Common cause failure — The failure of two or more apparently independent components or systems due to the occurrence of a single event.

Common mode failure — The result of an event which, because of dependencies, causes a coincidence of failure states of components in two or more separate branches of a redundant system leading to the system failing to perform its defined function.

Component — An item which is not operationally useful by itself but is an element of a system and is of such construction that it is not practically or economically amenable to further disassembly for maintenance or repair purposes.

Confidence limits — End points of the confidence interval that is believed to include the population parameter with a specified degree of confidence.

Cumulative probability — The probability that a random variable, x, lies between some lower limit, usually 0 or $-\infty$, and some upper limit determined by a specific value of x.

Failure mode — A specific manner in which the component under investigation could malfunction.

Failed state — The condition of a component or system during the time when it is subject to a failure or fault.

Fractional dead time — The mean proportion of the total relevant time that a component or system is in the failed state.

Hazard — A set of conditions in the operation of a product or system with the potential for initiating an accident sequence.

Hazardous material — A material which without proper controls could cause damage to property or danger to life.

Maintainability — The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources.

Maintenance — The combination of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function.

Mean time between failures — The total measured operating time of a population of components divided by the total number of failures. (For repairable items. For non-repairable items the definition is amended to reflect this and the term mean time to (first) failure is used).

Non systematic (random) events — Events which do not represent a fixed deviation from the time value and have an implication of chance.

Probability — If an event occurs x times during a series of n independent experiments then the probability of that event is the ratio of (x/n) as the total number of experiments tends to infinity.

Probability density function — If x is a random continuous variable then the probability density function of x is defined as the first derivative of the cumulative probability function with respect to x.

Probability distribution — The way, in some mathematical form, in which the probability is dependent on some continuous variable of a number of discrete values of a variable.

Product liability — The onus on a producer or distributor for the condition of a product that causes an event by which someone suffers loss or harm.

Quality control — The operational techniques and activities that sustain the product or service quality to specified requirements. It is also the use of such techniques and activities.

Random — The unpredictable occurrence of events in space, in time or in both space and time.

Redundancy — The performance of the same overall function by a number of independent but identical means.

Reliability — The characteristic of a device expressed as the probability of it performing in the manner desired for a specified period of time under specified operating conditions.

Repairable — The ability of a component or system to be returned to its defined operating state by practical and economic maintenance operations.

Risk — The combined effect of the probability of occurrence of an undesirable event, and the magnitude of the event.

Safety — Freedom from unacceptable risks to life or damage to property.

System — A combination of components which are interconnected in such a way as to perform some specific overall function.

Systematic errors — Errors which represent a fixed deviation from the time or standard value.

APPENDIX 1

ANALYTICAL DETERMINATION OF PROBABILITY OF FAILURE

Many structures that are subject to design appraisal and inspection by the Society contain forgings, castings and weldments. These are all areas which can contain defects whose acceptability can be assessed by fracture mechanics methods. As an extension of the basic acceptance of defects, probabilistic methods can be used to model the defect and the critical defect. The probability of failure for a given situation is the probability that the existing defect exceeds the local crack tolerance.

Based on PD6493 (41) the maximum allowable defect size, $\bar{a}_m$, may be calculated as:

$$\bar{a}_m = \frac{\delta E \sigma_y}{2\pi\sigma_1^2} \text{ for } \sigma_1 \leq 0{\cdot}5\sigma_y$$

$$= \frac{E\delta}{2\pi(\sigma_1 - 0{\cdot}25\sigma_y)} \text{ for } \sigma_1 > 0{\cdot}5\,\sigma_y$$

where $\bar{a}_m$ is the half length of a through thickness flaw

δ is the crack tip opening displacement (CTOD)

E is Young's modulus

σ_y is material yield strength

σ_1 is nominal stress

The value of δ can be modelled by a probability density function (p.d.f.) to represent material variability.

Inspection will not detect all defects and hence a probability density function can be used to model the size of defect that escapes detection.

If f(a) is the p.d.f. of the flaw and g(a_c) is the corresponding p.d.f. of the critical defect then the probability of failure P_f can be determined as:

$$P_f = \int_0^\infty \int_0^a g(a_c)\, da_c\, f(a)\, da$$

If the two distributions are both normal or lognormal then exact solution is directly achievable. In other cases numerical integration is required.

By way of example consider a weld, in the as welded condition, in BS 4360 Grade 50D steel at 0°C. Johnston has published data on the distribution of toughness in this material (42).

At 0°C CTOD has a mean value of 1·2 mm and a standard deviation (s.d.) of 0·125 mm.

The log normal distribution is used where the p.d.f. is:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma x} \exp\left[-\tfrac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2\right]$$

and the mean = exp ($\mu + \frac{1}{2}\sigma^2$)

and the s.d. = mean exp [(σ^2) − 1]$^{\frac{1}{2}}$

Hence in this example $\mu_c = 0{\cdot}177$
and $\sigma_c = 0{\cdot}104$.
The material properties are assumed to be

$$E = 207000 \text{ MPa}$$
$$\sigma_y = 450 \text{ MPa}$$

The operating stress is equal to half the yield stress and the residual stress is equal to the yield stress giving a nominal stress, σ_1, as follows:

$$\sigma_1 = \sigma_y + \tfrac{1}{2}\sigma_y = \tfrac{3}{2}\,\sigma_y$$

From the relation to CTOD the critical defect half length, $\bar{a}_m$ becomes $\bar{a}_m = 58{\cdot}57\,\delta$

The Marshall committee (43) suggests that the mean size of defect, a, remaining in a weldment is 6·25 mm with a standard deviation of 6·25 mm.

Assuming a lognormal distribution:

$$\mu_a = 1{\cdot}486$$
$$\sigma_a = 0{\cdot}833$$

Failure will occur when:

$$a > a_c$$

But $a_c = 117{\cdot}14\delta$ if the critical defect length a_c is equal to twice the allowable defect half length according to PD6493 (i.e. $a_c = 2\,\bar{a}_m$)

Hence $a > 117{\cdot}14\delta$

The safety margin (s.m.) in terms of standard deviations above mean can be determined as:

$$\text{s.m.} = \frac{\mu_{ac} - \mu_a}{\sqrt{\sigma_{ac}^{\ 2} + \sigma_a^{\ 2}}}$$

Hence in this case:

$$\text{s.m.} = \frac{4{\cdot}88 - 1{\cdot}486}{\sqrt{(0{\cdot}104^2 + 0{\cdot}833^2)}} = 4{\cdot}043$$

(note μ_{ac} = ln 117·14 × 0·177)

and hence the probability of failure from standard tables can be shown to be:

$$P_f = 2{\cdot}6 \times 10^{-5}$$

By this type of approach an estimate of reliability can be obtained. This can be extremely useful in instances where failures are rare or where no experience is available. Similarly, the probability of failure can be determined (6) for structural components (see also Appendix 6) allowing for the variability of the applied load, material properties, dimensional accuracy and constructional tolerances (44).

APPENDIX 2

EXAMPLES OF PERFORMANCE AND RELIABILITY DATA

To illustrate the form of reliability information available from the Society's Technical Records Office Database some typical examples which have been extracted are given here. Some of this data has been used in the analysis of probability of failure through FTA.

(a) **Ship Hull Structural Data**
Damage incidents for gas ships have been compiled for two of the four distinct ship regions:
(1) Fore-end
(2) Midship region in way of cargo tanks

These are given in Tables 8-9 respectively covering the years 1960–1978 for the Classed fleet. For the midship region they have been broken down to sub-system level. These incidents are given for all gas ships in Table 10 having a service life of 418 ship years.

(b) **Ships Machinery Reliability Information**
Typical examples of machinery reliability information have been extracted for ships built between 1st January 1970 and 31st December 1981 in the Classed fleet:

(i) Main oil engines of 1000 kW and over with a rotational speed in excess of 300 rev/min.

(ii) Main oil engines of 1000 kW and over with a rotational speed of less than 300 rev/min.

(iii) Oil engine main gearing rated at 1000 kW and over.

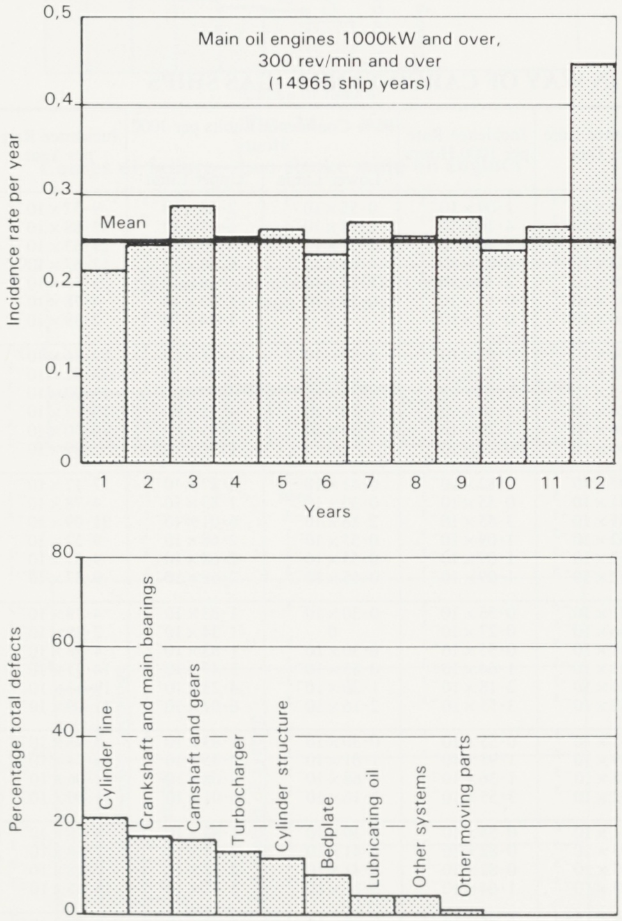


Fig. 12

Defects in main oil engines (≧300 rpm)

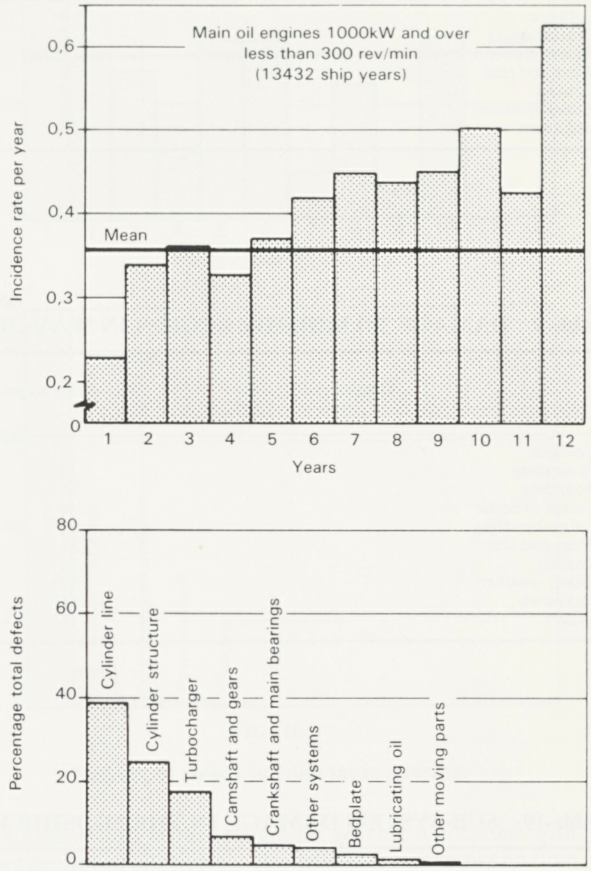


Fig. 13

Defects in main oil engines (≦300 rpm)

(iv) Steam turbine main gearing rated at 1000 kW and over.

(v) Main boilers rated at 1000 kW and over.

In each case the principal information is presented in the form of the annual incidence rate of defects for each year of service and a bar chart which identifies the percentage of the total number of defects attributed to each major component or sub system. In each case a mean incidence rate over the twelve year period, assuming a Poisson process, is determined. In most cases the latter few years of service are represented by a relatively small number of ships and so the results are of relatively low significance.

Example (i) covers the field of medium speed main propulsion oil engines and is illustrated in Fig. 12. The annual incidence rate is essentially constant over the 12 years considered based on a sample service life of 14965 ship years. The bar chart shows that no one component or sub system is clearly responsible for the major portion of the defects.

Example (ii) covers the field of slow speed main propulsion oil engines and is illustrated in Fig. 13. The annual incidence rate is clearly time dependent and shows a significant increase over the 12 years considered. The sample service life is 13432 ship years. The mean incidence rate of about 0·36 defects per year is considerably higher than that for medium speed oil engines which is shown to be about 0·25 defects per year. The cylinder line and structure account for about 63% of defects.

Table 8 DAMAGE TO THE FORE-END BY CAUSE—GAS SHIPS

Cause	No. of Damages	Incidence Rate per Day	Incidence Rate per 1000 Hours	95% Confidence Limits per 1000 Hours		Incidence Rate per Year
				Lower Limit	Upper Limit	
Collision	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
Grounding	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}56\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}82\times10^{-3}$	$4{\cdot}78\times10^{-3}$
Excess pressure	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
Wear and tear	7	$4{\cdot}59\times10^{-5}$	$1{\cdot}91\times10^{-3}$	$1{\cdot}01\times10^{-3}$	$3{\cdot}85\times10^{-3}$	$16{\cdot}74\times10^{-3}$
Contact	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
Heavy weather	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$
Unknown	13	$8{\cdot}52\times10^{-5}$	$3{\cdot}55\times10^{-3}$	$2{\cdot}16\times10^{-3}$	$6{\cdot}01\times10^{-3}$	$31{\cdot}09\times10^{-3}$

Table 9 DAMAGE TO MIDSHIP REGION IN WAY OF CARGO TANKS BY CAUSE—GAS SHIPS

Cause	No. of Damages	Incidence Rate per Day	Incidence Rate per 1000 Hours	95% Confidence Limits per 1000 Hours		Incidence Rate per Year
				Lower Limit	Upper Limit	
Collision	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$
Grounding	8	$5{\cdot}24\times10^{-5}$	$2{\cdot}18\times10^{-3}$	$1{\cdot}20\times10^{-3}$	$4{\cdot}23\times10^{-3}$	$19{\cdot}13\times10^{-3}$
Pounding	3	$1{\cdot}97\times10^{-5}$	$0{\cdot}82\times10^{-3}$	$0{\cdot}41\times10^{-3}$	$2{\cdot}27\times10^{-3}$	$7{\cdot}18\times10^{-3}$
Excess pressure	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
Cargo handling	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
Wear and tear	25	$16{\cdot}38\times10^{-5}$	$6{\cdot}83\times10^{-3}$	$4{\cdot}67\times10^{-3}$	$10{\cdot}02\times10^{-3}$	$59{\cdot}80\times10^{-3}$
Contact	14	$9{\cdot}17\times10^{-5}$	$3{\cdot}82\times10^{-3}$	$2{\cdot}34\times10^{-3}$	$6{\cdot}36\times10^{-3}$	$33{\cdot}49\times10^{-3}$
Heavy weather	17	$11{\cdot}14\times10^{-5}$	$4{\cdot}64\times10^{-3}$	$2{\cdot}95\times10^{-3}$	$7{\cdot}37\times10^{-3}$	$40{\cdot}66\times10^{-3}$
Unknown	58	$38{\cdot}01\times10^{-5}$	$15{\cdot}84\times10^{-3}$	$12{\cdot}29\times10^{-3}$	$20{\cdot}42\times10^{-3}$	$138{\cdot}73\times10^{-3}$
Others	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$

Table 10 SUB-SYSTEM DAMAGE IN THE MIDSHIP REGION IN WAY OF CARGO TANKS—GAS SHIPS

Sub-system	Cause	Number of Damages	Incidence Rate per Day	Incidence Rate per 1000 Hours	95% Confidence Limits per 1000 Hours		Incidence Rate per Year
					Lower Limit	Upper Limit	
Bottom shell structure	Collision	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
	Wear and tear	15	$9{\cdot}83\times10^{-5}$	$4{\cdot}10\times10^{-3}$	$2{\cdot}54\times10^{-3}$	$6{\cdot}69\times10^{-3}$	$35{\cdot}88\times10^{-3}$
	Grounding	9	$5{\cdot}90\times10^{-5}$	$2{\cdot}46\times10^{-3}$	$1{\cdot}37\times10^{-3}$	$4{\cdot}59\times10^{-3}$	$21{\cdot}53\times10^{-3}$
	Unknown	22	$14{\cdot}42\times10^{-5}$	$6{\cdot}01\times10^{-3}$	$4{\cdot}01\times10^{-3}$	$9{\cdot}04\times10^{-3}$	$52{\cdot}62\times10^{-3}$
	Heavy weather	9	$5{\cdot}90\times10^{-5}$	$2{\cdot}46\times10^{-3}$	$1{\cdot}37\times10^{-3}$	$4{\cdot}64\times10^{-3}$	$21{\cdot}53\times10^{-3}$
	Pounding	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Others	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
Sideshell structure	Unknown	29	$19{\cdot}00\times10^{-5}$	$7{\cdot}92\times10^{-3}$	$5{\cdot}57\times10^{-3}$	$11{\cdot}33\times10^{-3}$	$69{\cdot}36\times10^{-3}$
	Wear and tear	10	$6{\cdot}55\times10^{-5}$	$2{\cdot}73\times10^{-3}$	$1{\cdot}56\times10^{-3}$	$4{\cdot}94\times10^{-3}$	$23{\cdot}92\times10^{-3}$
	Collision	10	$6{\cdot}55\times10^{-5}$	$2{\cdot}73\times10^{-3}$	$1{\cdot}56\times10^{-3}$	$4{\cdot}94\times10^{-3}$	$23{\cdot}92\times10^{-3}$
	Heavy weather	8	$5{\cdot}24\times10^{-5}$	$2{\cdot}18\times10^{-3}$	$1{\cdot}20\times10^{-3}$	$4{\cdot}23\times10^{-3}$	$19{\cdot}13\times10^{-3}$
	Contact	12	$7{\cdot}86\times10^{-5}$	$3{\cdot}28\times10^{-3}$	$1{\cdot}94\times10^{-3}$	$5{\cdot}65\times10^{-3}$	$28{\cdot}70\times10^{-3}$
	Excess pressure	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
Transverse bulkhead structure	Contact	3	$1{\cdot}97\times10^{-5}$	$0{\cdot}82\times10^{-3}$	$0{\cdot}41\times10^{-3}$	$2{\cdot}27\times10^{-3}$	$7{\cdot}17\times10^{-3}$
	Excess pressure	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Unknown	13	$8{\cdot}51\times10^{-5}$	$3{\cdot}55\times10^{-3}$	$2{\cdot}16\times10^{-3}$	$6{\cdot}01\times10^{-3}$	$31{\cdot}09\times10^{-3}$
	Heavy weather	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
	Wear and tear	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
	Collision	4	$2{\cdot}62\times10^{-5}$	$1{\cdot}09\times10^{-3}$	$0{\cdot}55\times10^{-3}$	$2{\cdot}68\times10^{-3}$	$9{\cdot}57\times10^{-3}$
Longitudinal bulkhead structure	Collision	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Grounding	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
	Excess pressure	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Wear and tear	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$
	Heavy weather	8	$5{\cdot}24\times10^{-5}$	$2{\cdot}18\times10^{-3}$	$1{\cdot}20\times10^{-3}$	$4{\cdot}23\times10^{-3}$	$19{\cdot}13\times10^{-3}$
	Unknown	13	$8{\cdot}52\times10^{-5}$	$3{\cdot}55\times10^{-3}$	$2{\cdot}16\times10^{-3}$	$6{\cdot}01\times10^{-3}$	$31{\cdot}09\times10^{-3}$
Tank top structure	Collision	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Wear and tear	7	$4{\cdot}59\times10^{-5}$	$1{\cdot}91\times10^{-3}$	$1{\cdot}01\times10^{-3}$	$3{\cdot}85\times10^{-3}$	$16{\cdot}74\times10^{-3}$
	Heavy weather	5	$3{\cdot}28\times10^{-5}$	$1{\cdot}36\times10^{-3}$	$0{\cdot}68\times10^{-3}$	$3{\cdot}08\times10^{-3}$	$11{\cdot}96\times10^{-3}$
	Unknown	13	$8{\cdot}52\times10^{-5}$	$3{\cdot}55\times10^{-3}$	$2{\cdot}16\times10^{-3}$	$6{\cdot}01\times10^{-3}$	$31{\cdot}09\times10^{-3}$
Transverse structure	Collision	2	$1{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Wear and tear	3	$1{\cdot}97\times10^{-5}$	$0{\cdot}82\times10^{-3}$	$0{\cdot}41\times10^{-3}$	$2{\cdot}27\times10^{-3}$	$7{\cdot}18\times10^{-3}$
	Heavy weather	3	$1{\cdot}97\times10^{-5}$	$0{\cdot}82\times10^{-3}$	$0{\cdot}41\times10^{-3}$	$2{\cdot}27\times10^{-3}$	$7{\cdot}18\times10^{-3}$
	Unknown	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$
Longitudinal structure	Collision	2	$11{\cdot}31\times10^{-5}$	$0{\cdot}55\times10^{-3}$	$0{\cdot}30\times10^{-3}$	$1{\cdot}83\times10^{-3}$	$4{\cdot}78\times10^{-3}$
	Heavy weather	3	$1{\cdot}97\times10^{-5}$	$0{\cdot}82\times10^{-3}$	$0{\cdot}41\times10^{-3}$	$2{\cdot}27\times10^{-3}$	$7{\cdot}18\times10^{-3}$
	Cargo handling	1	$0{\cdot}66\times10^{-5}$	$0{\cdot}27\times10^{-3}$	0	$1{\cdot}34\times10^{-3}$	$2{\cdot}39\times10^{-3}$
	Wear and tear	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$
	Unknown	6	$3{\cdot}93\times10^{-5}$	$1{\cdot}64\times10^{-3}$	$0{\cdot}85\times10^{-3}$	$3{\cdot}47\times10^{-3}$	$14{\cdot}35\times10^{-3}$

Both examples (i) and (ii) illustrate one of the disadvantages of deriving reliability data from survey reports. Minor failures which significantly alter the failure rate for oil engines are not recorded, noteably fuel system faults. The corresponding bar chart for two stroke main oil engines on 15 freighters during the period from 1972 to 1980 is shown in Fig. 14 (45). Over a period of 97 ship years of operation, 4087 damages were registered of which 1110 required stopping of the main engine. The corresponding incidence rates are 11·4 per ship year for loss of propulsive power and 42·1 per ship year for all defects. It is anticipated that the data now being collated by TRO from owners will assist in providing reliability data which will include the type of stoppage not currently identified by Classification survey reports.

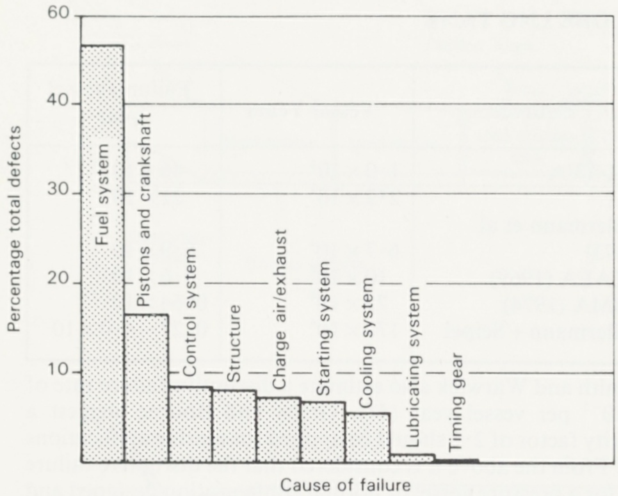


FIG. 14

Causes of failure—two stroke main oil engines

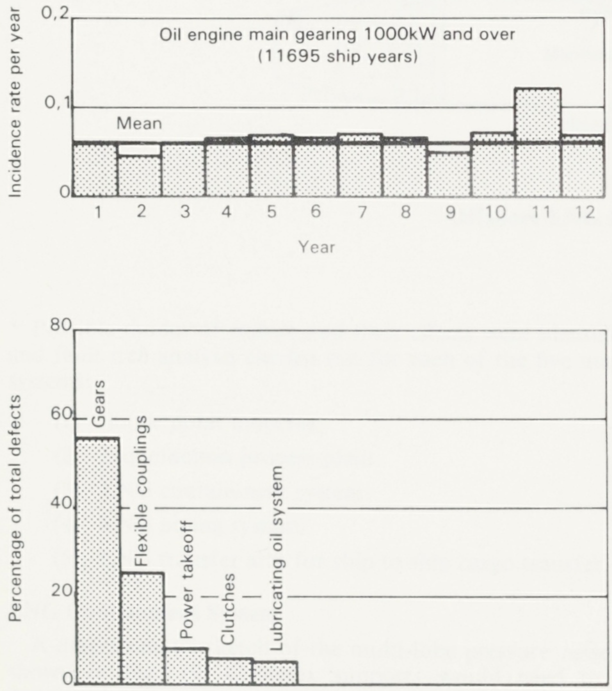


FIG. 15

Defects in oil engine main gearing

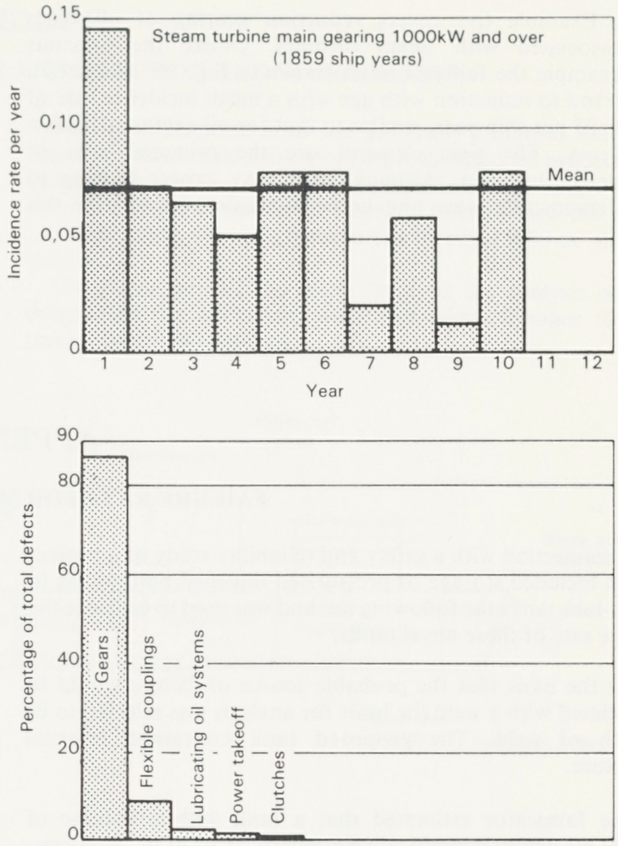


FIG. 16

Defects in steam turbine main gearing

Example (iii) covers reduction gearing associated with medium speed oil engines. The incidence rate shows no time dependence as shown in Fig. 15. The principal areas of defect location are the gear elements and flexible couplings. The mean incidence rate is about 0·06 per ship year.

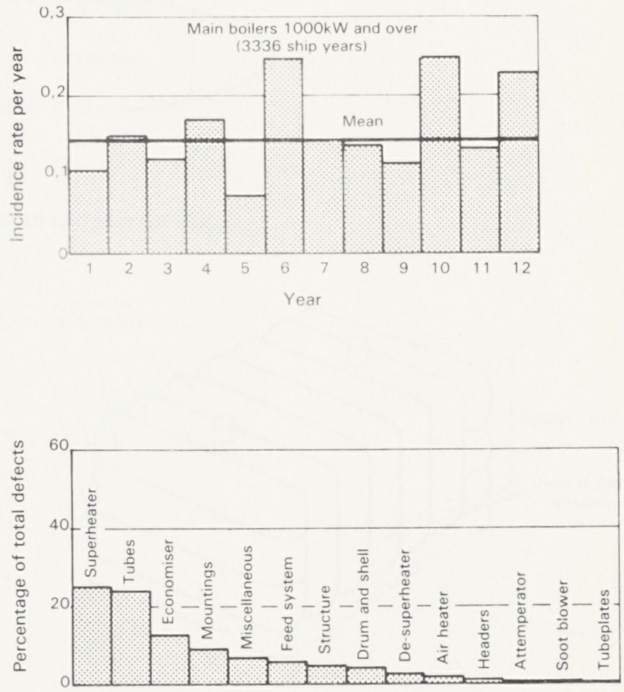


FIG. 17

Defects in main boilers

Example (iv) covers reduction gearing of all types associated with steam turbines. Unlike the previous example the failure rate as shown in Fig. 16 illustrates a trend to reduction with age with a mean incidence rate of 0·07 per ship year, similar to that for oil engine reduction gears. The gear elements are the principal area of defect location. Although one may expect gearing to demonstrate wear and hence increasing failure rate this does not appear to be the case with steam turbine reduction gearing.

Example (v) for main boilers, like the examples of gearing, should be reasonably complete since survey reports should identify the majority of significant defects. The incidence rate shows considerable fluctuation about a mean value of 0·14 per ship year with the defects well distributed throughout the boiler, as shown in Fig. 17.

APPENDIX 3

FAILURE RATE FOR MULTI-LOBE LNG TANK

In connection with a safety and reliability study of a project which included storage of pressurised liquefied natural gas in multi-lobe tanks the following method was used to estimate the failure rate of these novel tanks.

On the basis that the probable source of failure would be associated with a weld the basis for analysis was selected to be length of weld. The proposed tank contained internal structure.

The fabricator estimated that a tank with a volume of 19500 m^3 would contain a weld length of 9370 m. A corresponding spherical tank with no plate dimension larger than 3 m would contain a weld length of about 2500 m. Assuming a corresponding standard of construction and inspection the probability of failure at a weld of the multi-lobe tank is likely to be about 3·75 times higher than for a spherical tank.

The WASH-1285 study (46) states the following 90% confidence upper bound values for disruptive failure of non-nuclear pressure vessels:

Source	Vessel Years	Failure/vessel year
EEI-TVA	$1{\cdot}0 \times 10^4$	46×10^{-5}
EEI	$2{\cdot}2 \times 10^4$	21×10^{-5}
Kellermann et al (1973)	$6{\cdot}7 \times 10^4$	$6{\cdot}9 \times 10^{-5}$
UKAEA (1969)	10×10^4	$4{\cdot}6 \times 10^{-5}$
ABMA (1974)	72×10^4	$0{\cdot}64 \times 10^{-5}$
Kellermann + Seipel	170×10^4	$0{\cdot}27 - 4{\cdot}0 \times 10^{-5}$

Smith and Warwick also estimate a disruptive failure rate of 4×10^{-5} per vessel year (47). Green and Bourne suggest a severity factor of 2·0 should be applied for marine applications (17). From the above it is considered that the disruptive failure rate for a pressure vessel of normal configuration designed and built in accordance with a recognised code should be about 2×10^{-4}/year or better. In the case of the multi-lobe tank under consideration for marine application a disruptive failure rate of about 15×10^{-4}/year is considered appropriate.

APPENDIX 4

FMEA AND FTA FOR OFFSHORE LNG LIQUEFACTION AND STORAGE SHIP

Design Concept

An example of a failure analysis on the design and operational concepts are given here for a project which is at an early stage of development.

The Society carried out a safety and reliability study of a new type of offshore LNG ship, see Fig. 18. The proposal is to liquefy and transport natural gas at a temperature of about $-130°C$ and at a pressure of about 4 bar from an offshore gas field to a mainland terminal.

The basic proposal is to use gas from a marine well and transfer it via a single point mooring to an attached process and storage ship, where it would be liquefied by a single train process plant and passed to storage tanks aboard the ship. Later the LNG would be transported by two 15000 m^3 shuttle ships.

The major part of the study involved the analysis of the design and the operation, with particular reference to gas leakage and LNG spillage.

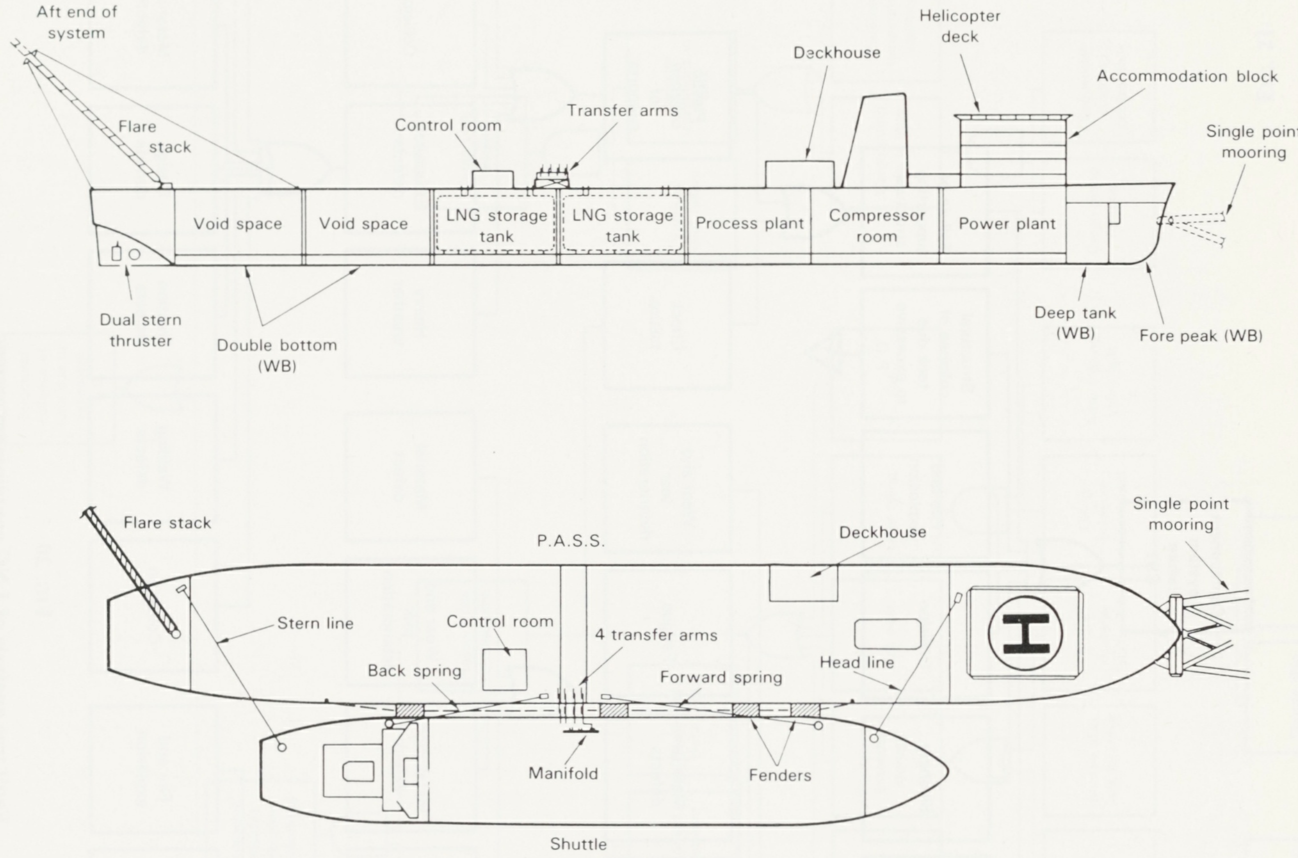


Fig. 18

Offshore LNG liquefaction and storage ship

Possible modes of failure and their effects were identified, and fault tree analysis carried out for each of the five major systems:

(1) Single point mooring.

(2) Liquefaction process plant.

(3) LNG containment system.

(4) LNG piping system.

(5) LNG transfer arm for ship to ship cargo transfer.

LNG Containment System

A diagrammatic sketch of the multi-lobe pressure vessel is shown in Fig. 19. Complex supports would need to be developed at each lobe to transfer the static and dynamic loads to the double bottom floors and plate longitudinals. Anti-roll chocks would also be fitted.

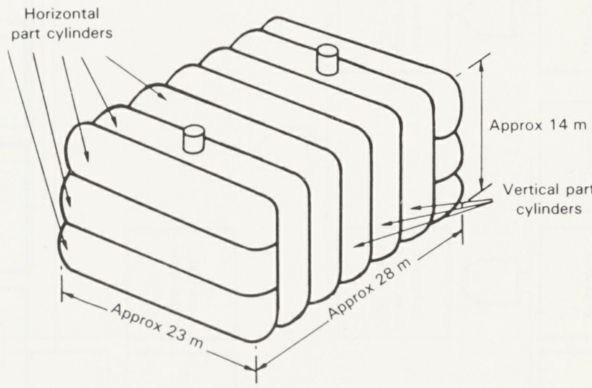


Fig. 19

Multi-lobe LNG pressure vessel

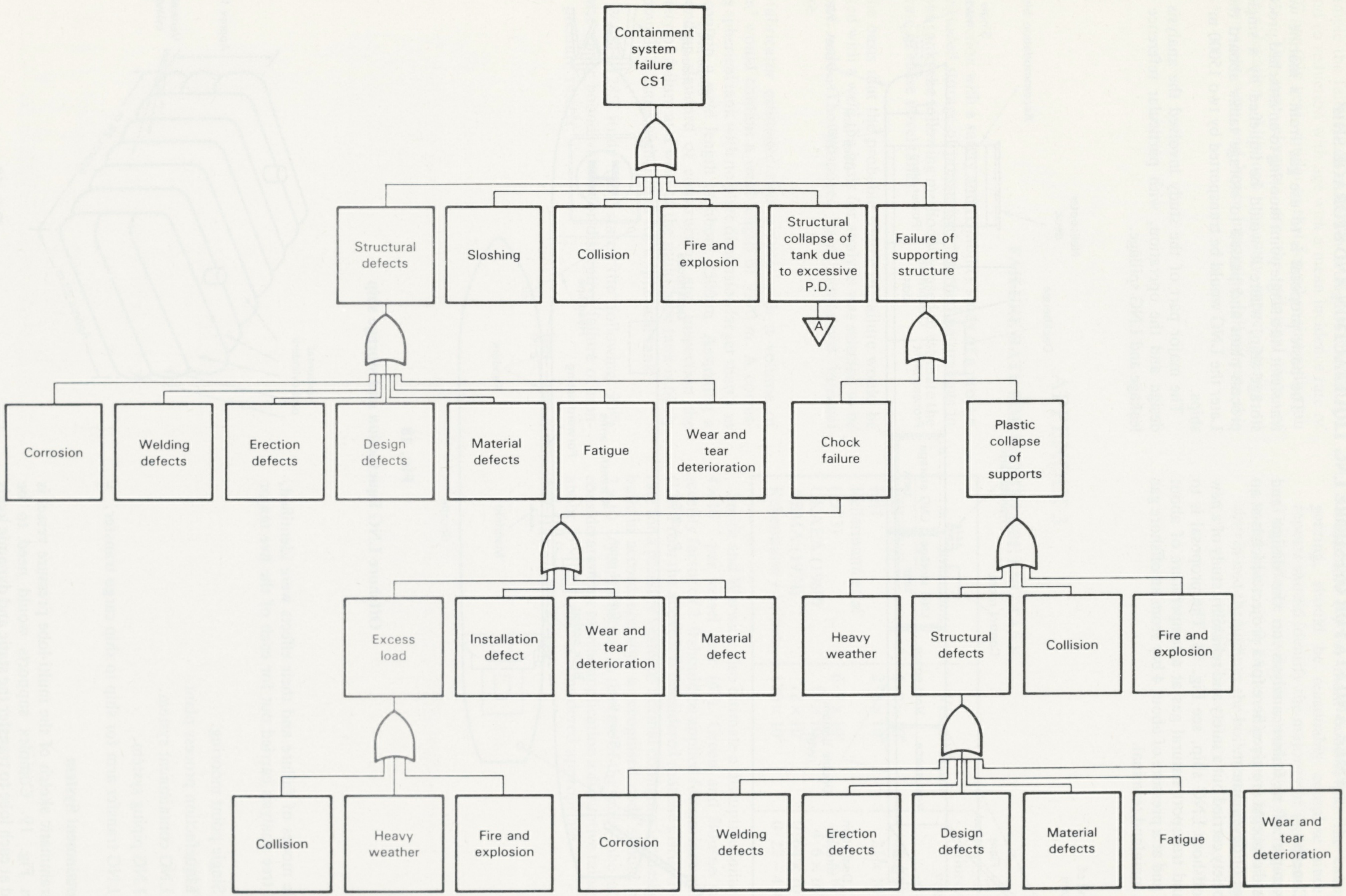


FIG. 20

Fault tree analysis of LNG containment system

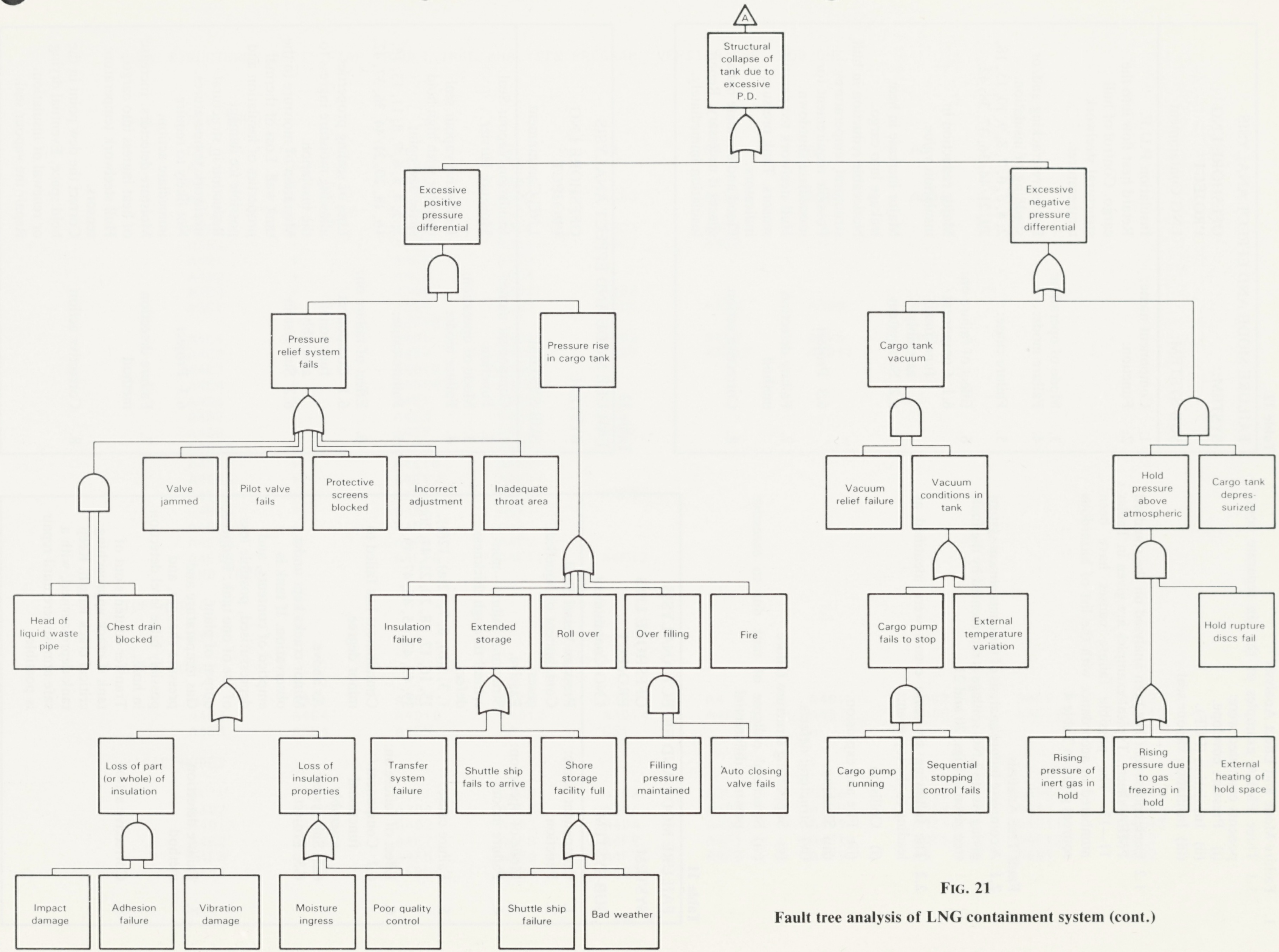


FIG. 21

Fault tree analysis of LNG containment system (cont.)

1. Failure Mode and Effect Analysis
   1.1 Three FMEA examples of the six separate components evaluated were:
      (i) Pressure envelope.
      (ii) Insulation (PUF).
      (iii) Insulation vapour seal.

   1.2 Each component has been analysed on the standard FMEA sheets. Typical examples are given in Tables 11—13. The possible failure causes have been numbered in accordance with the list of hazardous sources given in Table 4.

2. Fault Tree Analysis
   2.1 A complete failure analysis of the containment system giving rise to LNG spillage is represented by the fault tree given in Figs. 20 and 21.

   2.2 The following six main events were identified as leading to the top event:
      (i) Collision.
      (ii) Fire and explosion.
      (iii) Sloshing.
      (iv) Structural defects.
      (v) Supporting structure failure.
      (vi) Structural collapse of tank due to excessive pressure differential.

Table 11

FAILURE MODE AND EFFECT ANALYSIS	
SYSTEM:	OFFSHORE LNG PROJECT
SUB-SYSTEM:	LNG Containment
1. Component name:	Pressure Vessel Shell.
2. Function:	Containment of liquefied gases.
3. Mode of operation:	Passive.
4. Failure mode:	Structural failure—non-critical through thickness defect.
5. Failure cause:	1, 3, 5(b), 6, 7, 12(a), 12(b), 15, 16, 17, 18, 20, 21/44, 36, 39, 42, 43, 45, 46, 47, 49.
6. Effect of failure on:	
6.1 Component/ functional assembly	Containment has failed to minor degree.
6.2 Sub-system	As above.
6.3 Project	Minor cracks kept under observation. If tank is emptied of contents, and depressurised, possible loss of use of one tank. Reduced output of plant.
7. Failure detection method	Gas temperature and pressure changes, and possibly bilge level detection in hold.
8. Corrective action	Transfer contents out of tank if crack approaching critical crack length. Keep tank depressurised, with a safe atmosphere until repair is possible.

Table 12

FAILURE MODE AND EFFECT ANALYSIS	
SYSTEM:	OFFSHORE LNG PROJECT
SUB-SYSTEM:	LNG Containment
1. Component name:	Insulation P.U.F.
2. Function:	Retard heat flow into the cargo. Control of hull structural steelwork temperatures.
3. Mode of operation:	—
4. Failure mode:	Extensive cracking and/or shedding of insulation.
5. Failure cause:	2, 4, 5, 6, 7, 8, 9, 10, 15, 18, 20, 21/44, 36, 37, 38, 42.
6. Effect of failure on:	
6.1 Component/ functional assembly	Major reduction in insulation value.
6.2 Sub-system	Major increase in heat leakage into cargo. Noticeable reduction in hull structural temperatures.
6.3 Project	Possible requirement for immediate shutdown.
7. Failure detection method	Hull steelwork temperature sensors. Tank pressure indicators.
8. Corrective action	Flood and circulate ballast spaces if necessary. Repair insulation immediately.

Table 13

FAILURE MODE AND EFFECT ANALYSIS	
SYSTEM:	OFFSHORE LNG PROJECT
SUB-SYSTEM:	LNG Containment
1. Component name:	Insulation Vapour Seal.
2. Function:	Moisture barrier.
3. Mode of operation:	—
4. Failure mode:	Ineffective vapour seal together with high hold space dew point.
5. Failure cause:	1, 2, 4, 5, 6, 7, 8, 11, 13, 15, 16, 18, 20, 21/44, 36, 37, 42.
6. Effect of failure on:	
6.1 Component/ functional assembly	Loss of sealing properties allowing moisture ingress to the insulation.
6.2 Sub-system	Migration of moisture to the tank wall. Loss of thermal properties of insulation and possible ice damage. Reduction in structural steelwork temperatures.
6.3 Project	Not likely to require immediate action.
7. Failure detection method	Moisture detectors. Increase of heat ingress into cargo. Hull steelwork temperature sensors.
8. Corrective action	Correct the dew point in the hold space. Eventual drying or renewal of insulation. Repair the vapour seal.

HULL STRUCTURES DEPT FTAP FAULT TREE ANALYSIS PROGRAM VERSION ONE MOD ONE

FAULT TREE INPUT

CS1	+	A1	A2	A3	A4	A5	A6
A3	+	A3B1	A3B2				
A4	+	A4B1	A4B2				
A6	+	A6B1	A6B2	A6B3	A6B4	A6B5	A6B6
		A6B7					
A3B1	+	A3C1	A3C2	A3C3	A3C4		
A3B2	+	A3C5	A3C6	A3C7	A3C8		
A4B1	*	A4C1	A4C2				
A4B2	+	A4C3	A4C4				
A3C4	+	A3D1	A3D2	A3D3			
A3C7	+	A3D4	A3D5	A3D6	A3D7	A3D8	A3D9
		A3D10					
A4C1	+	A4D1	A4D2	A4D3	A4D4	A4D5	A4D6
A4C2	+	A4D7	A4D8	A4D9	A4D10	A4D11	
A4C3	*	A4D12	A4D13				
A4C4	*	A4D14	A4D15				
A4D6	*	A4E1	A4E2				
A4D7	+	A4E3	A4E4				
A4D8	+	A4E5	A4E6	A4E7			
A4D10	*	A4E8	A4E9				
A4D12	+	A4E10	A4E11				
A4D14	*	A4E12	A4E13				
A4E3	+	A4F1	A4F2	A4F3			
A4E4	+	A4F4	A4F5				
A4E5	+	A4F6	A4F7				
A4E10	*	A4F8	A4F9				
A4E12	+	A4F10	A4F11	A4F12			
END TREE							

TOP NODE(S)

CS1

GATE NODES

A3	A3B1	A3B2	A3C4	A3C7	A4	A4B1	A4B2	A4C1	A4C2
A4C3	A4C4	A4D10	A4D12	A4D14	A4D6	A4D7	A4D8	A4E10	A4E12
A4E3	A4E4	A4E5	A6	CS1					

BASIC NODES

A1	A2	A3C1	A3C2	A3C3	A3C5	A3C6	A3C8	A3D1	A3D10
A3D2	A3D3	A3D4	A3D5	A3D6	A3D7	A3D8	A3D9	A4D1	A4D11
A4D13	A4D15	A4D2	A4D3	A4D4	A4D5	A4D9	A4E1	A4E11	A4E13
A4E2	A4E6	A4E7	A4F8	A4F9	A4F1	A4F10	A4F11	A4F12	A4F2
A4F3	A4F4	A4F5	A4F6	A4F7	A4F8	A4F9	A5	A6B1	A6B2
A6B3	A6B4	A6B5	A6B6	A6B7					

FIG. 22

A N A L Y S I S   O F   P R I M A L   T R E E

IMPLICANTS IN TERMS OF BASIC EVENTS - IMPLICANTS FOR EVENT CS1

1	A6B7		31	A4D5	A4F3	61	A4D2	A4F3		91	A4F1	A4E2	A4F6	
2	A6B6		32	A4D5	A4F2	62	A4D2	A4F2		92	A4D9	A4E1	A4F2	
3	A6B5		33	A4D5	A4F1	63	A4D2	A4F1		93	A4D5	A4E8	A4F9	
4	A6B4		34	A4D5	A4E7	64	A4D2	A4E7		94	A4D4	A4E8	A4F9	
5	A6B3		35	A4D5	A4E6	65	A4D2	A4E6		95	A4D3	A4E8	A4F9	
6	A6B2		36	A4D5	A4D9	66	A4D2	A4D9		96	A4D2	A4E8	A4F9	
7	A6B1		37	A4D4	A4F7	67	A4D13	A4E11		97	A4D15	A4E13	A4F12	
8	A5		38	A4D4	A4F6	68	A4D11	A4D5		98	A4D15	A4E13	A4F11	
9	A3D9		39	A4D4	A4F5	69	A4D11	A4D4		99	A4D15	A4E13	A4F10	
10	A3D8		40	A4D4	A4F4	70	A4D11	A4D3		100	A4D15	A4F8	A4F9	
11	A3D7		41	A4D4	A4F3	71	A4D11	A4D2		101	A4D11	A4E1	A4E2	
12	A3D6		42	A4D4	A4F2	72	A4D1	A4F7		102	A4D1	A4E8	A4E9	
13	A3D5		43	A4D4	A4F1	73	A4D1	A4F6		103	A4F1	A4E2	A4E8	A4F9
14	A3D4		44	A4D4	A4E7	74	A4D1	A4F5						
15	A3D3		45	A4D4	A4E6	75	A4D1	A4F4						
16	A3D2		46	A4D4	A4D9	76	A4D1	A4F3						
17	A3D10		47	A4D3	A4F7	77	A4D1	A4F2						
18	A3D1		48	A4D3	A4F6	78	A4D1	A4F1						
19	A3C8		49	A4D3	A4F5	79	A4D1	A4E7						
20	A3C6		50	A4D3	A4F4	80	A4D1	A4E6						
21	A3C5		51	A4D3	A4F3	81	A4D1	A4D9						
22	A3C3		52	A4D3	A4F2	82	A4D1	A4D11						
23	A3C2		53	A4D3	A4F1	83	A4F1	A4E2	A4F7					
24	A3C1		54	A4D3	A4E7	84	A4F1	A4E2	A4F6					
25	A2		55	A4D3	A4E6	85	A4F1	A4E2	A4F5					
26	A1		56	A4D3	A4D9	86	A4F1	A4E2	A4F4					
27	A4D5	A4F7	57	A4D2	A4F7	87	A4F1	A4E2	A4F3					
28	A4D5	A4F6	58	A4D2	A4F6	88	A4F1	A4E2	A4F2					
29	A4D5	A4F5	59	A4D2	A4F5	89	A4F1	A4E2	A4F1					
30	A4D5	A4F4	60	A4D2	A4F4	90	A4F1	A4E2	A4F7					

FIG. 23

2.3 In order to obtain a list of the implicant sets of component failures and events, the fault tree given in Figs. 20 and 21 has been analysed using LR.FTAP. Each event has been given an identifier as shown in Table 14. Coding has been performed in a logical way in order that each event can be traced through the various levels leading to the undesirable top event of LNG spillage due to containment failure. 'A' relates to the first level down from the top event, 'B' to the second level down and so on. Part of the computer output is shown in Figs. 22 and 23. Note that a + sign represents an OR gate and an * sign represents an AND gate. The full analysis of the containment system gave 103 possible failure combinations which could give rise to LNG spillage. A reliability analysis using LR.FTREP is not shown here.

LNG Ship to Ship Transfer System

This analysis deals only with those failures associated with the LNG transfer arm system which could result in a release of LNG. The analysis considers the failure of one arm only and no consideration is given to 'knock-on' or domino effects on the adjacent arms. A sketch of a transfer arm is given in Fig. 24.

1. Failure Mode and Effect Analysis

1.1 Three FMEA examples of the seven individual component or component groups of the sub-system to be evaluated were:

(i) Powered arm control system.

(ii) Ship-board mooring equipment.

(iii) Mooring line.

1.2 Each component or component group has been analysed on the standard FMEA sheets. The examples are given in Tables 15—17. The possible failure causes have been numbered in accordance with the hazardous sources listed in Table 4.

2. Fault Tree Analysis

2.1 LNG release could result from any rupture of the transfer arm pipework, due to failure of the transfer arm or its piping, or due to operational errors, (i.e. disconnecting without stripping which may be necessary under certain conditions, perhaps failure of inert purging system).

Three main events have been identified as giving rise to LNG spillage from the LNG transfer system.

(i) Controlled spill.

(ii) Transfer arm failure.

(iii) Failure of piping, etc. on arm.

These are expanded in the fault tree, Fig. 25 and 26.

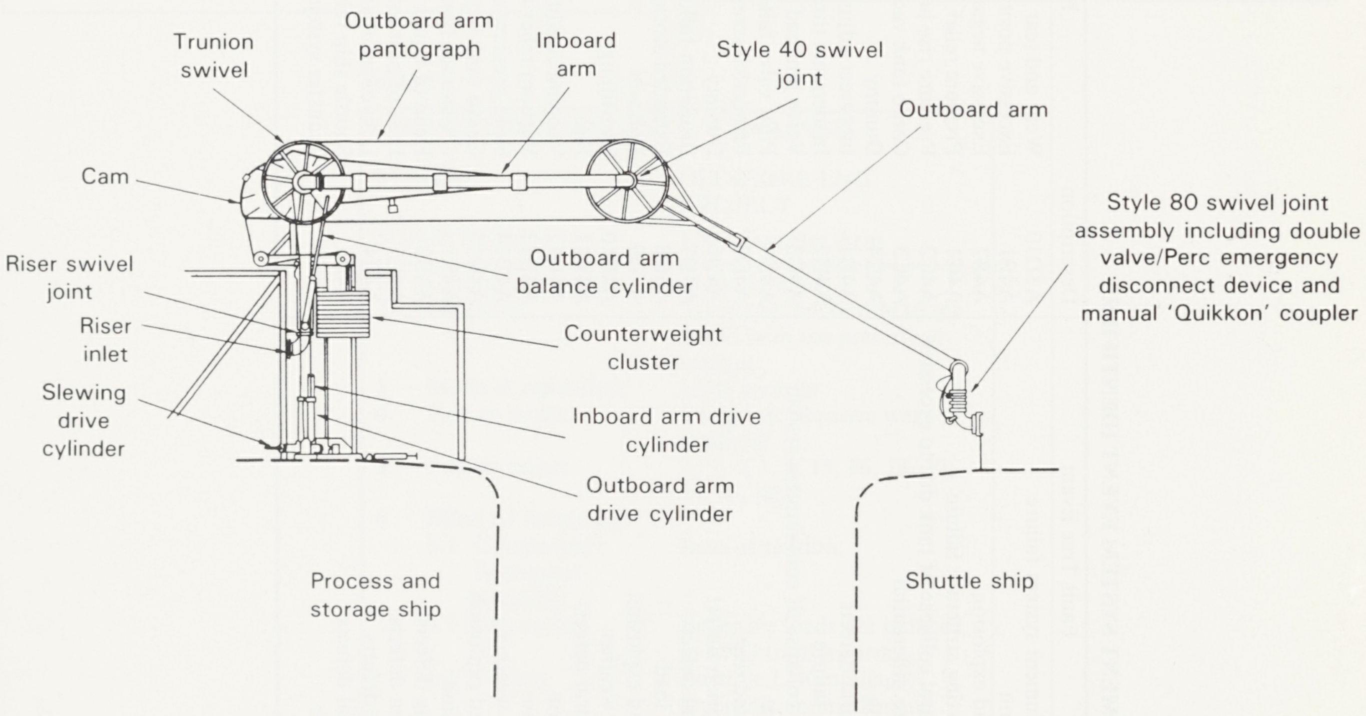


Fig. 24

LNG transfer arm (Chicksan)

Table 14 CONTAINMENT SYSTEM EVENT IDENTIFIERS

Description	Fault Tree Event	Description	Fault Tree Event	Description	Fault Tree Event
CS1	Containment system failure	A3D10	Wear and tear	A4E7	Shore storage facility full
A1	Collision	A4B1	Excessive positive pressure differential	A4E8	Filling pressure maintained
A2	Fire and explosion	A4B2	Excessive negative pressure differential	A4E9	Auto-closing valve fails
A3	Supporting structure failure	A4C1	Pressure relief system fails	A4E10	Cargo pump fails to stop
A4	Structural collapse of tank due to excessive pressure differential	A4C2	Pressure rise in cargo tank	A4E11	External temperature variation
A5	Sloshing	A4C3	Cargo tank vacuum	A4E12	Dummy
A6	Structural defects	A4C4	Dummy	A4E13	Hold rupture discs fails
A3B1	Chock failure	A4D1	Incorrect adjustment	A4F1	Impact damage
A3B2	Plastic collapse of containment system supports	A4D2	Inadequate throat area	A4F2	Adhesion failure
A3C1	Wear and tear	A4D3	Valve jammed	A4F3	Vibration damage
A3C2	Installation defect	A4D4	Pilot valve fails	A4F4	Moisture ingress
A3C3	Material defect	A4D5	Projective screens blocked	A4F5	Poor quality control
A3C4	Excess load	A4D6	Dummy	A4F6	Shuttle ship failure
A3C5	Fire and explosion	A4D7	Insulation failure	A4F7	Bad weather
A3C6	Heavy weather	A4D8	Extended storage	A4F8	Cargo pump running
A3C7	Structural defects	A4D9	Rollover	A4F9	Sequential stopping control fails
A3C8	Collision	A4D10	Overfilling	A4F10	Rising pressure of inert gas in hold
A3D1	Collision	A4D11	Fire	A4F11	Rising pressure due to gas freeing in hold
A3D2	Heavy weather	A4D12	Vacuum conditions in tank	A4F12	External heating of hold space
A3D3	Fire and explosion	A4D13	Vacuum relief failure	A6B1	Corrosion
A3D4	Corrosion	A4D14	Hold pressure above atmospheric	A6B2	Welding defects
A3D5	Welding defects	A4D15	Cargo tank depressurized	A6B3	Erection defects
A3D6	Erection defects	A4E1	Chestdrain blocked	A6B4	Design defects
A3D7	Design defects	A4E2	Head of liquid in waste pipe	A6B5	Material defects
A3D8	Material defects	A4E3	Loss of part (or whole) of insulation	A6B6	Fatigue
A3D9	Fatigue	A4E4	Loss of insulating properties	A6B7	Wear and tear
		A4E5	Shuttle ship fails to arrive		
		A4E6	Transfer system failure		

Table 15

FAILURE MODE AND EFFECT ANALYSIS		
SYSTEM:		OFFSHORE LNG PROJECT
SUB-SYSTEM:		LNG Transfer Arm
1.	Component name:	Powered Arm Control Systems.
2.	Function:	To control the movement of the arm, monitor its position at all times and provide emergency release system and valve actuation.
3.	Mode of operation:	Hydraulic/pneumatic/electric.
4.	Failure mode:	Loss of hydraulic/pneumatic/electric power, seizure/malfuction.
5.	Failure cause:	1, 2, 3, 5(a), 5(b), 5(c), 5(d), 6, 7, 8(a), 8(b), 9, 10(a), 11, 12(a), 12(b), 13(a & b), 15, 16, 17, 18, 20, 21, 26, 28, 36, 37, 41, 44, 45, 47.
6.	Effect of failure on:	
	6.1 Component/ functional assembly	Loss of function to a varying degree.
	6.2 Sub-system	Possible inability to respond to emergency commands which could result in arm fracture and uncontrollable LNG spill if arm parameters are exceeded.
	6.3 Project	Possible LNG spill with attendant hazard.
7.	Failure detection method	Control systems are self-monitoring.
8.	Corrective action	

Table 16

FAILURE MODE AND EFFECT ANALYSIS		
SYSTEM:		OFFSHORE LNG PROJECT
SUB-SYSTEM:		LNG Transfer Arm
1.	Component name:	Ship-Board Mooring Equipment (Process and storage ship (PASS) and/or Shuttle)
2.	Function:	To provide a means of securing the mooring line to the ship and to pre-tension the line.
3.	Mode of operation:	LNG transfer.
4.	Failure mode:	Structural failure of seats, internal damage to mechanism, damage to power line.
5.	Failure cause:	1, 3, 6, 7, 8, 15, 16, 17, 18, 20, 21, 44, 46.
6.	Effect of failure on:	
	6.1 Component/ functional assembly	Ship-board equipment unable to maintain tension in mooring lines.
	6.2 Sub-system	Excessive loads in LNG transfer arm.
	6.3 Project	Possible LNG spillage, possible cryogenic embrittlement, possible loss of PASS.
7.	Failure detection method	Total loss of tension shown by monitoring system audio—visual.
8.	Corrective action	Initiate emergency shutdown procedures. Investigate failure before replacing outfit item.

Table 17

FAILURE MODE AND EFFECT ANALYSIS		
SYSTEM:		OFFSHORE LNG PROJECT
SUB-SYSTEM:		LNG Transfer Arm
1.	Component name:	Mooring Line.
2.	Function:	To secure the Shuttle to the PASS with the prescribed tension.
3.	Mode of operation:	LNG transfer.
4.	Failure mode:	Snapping, abrasive wear (chafing).
5.	Failure cause:	1, 3, 6, 7, 8, 15, 16, 18, 20, 21, 44, 46.
6.	Effect of failure on:	
	6.1 Component/ functional assembly	Loss of tension.
	6.2 Sub-system	Excessive loads are induced in LNG transfer arm.
	6.3 Project	Possible LNG spillage, cryogenic embrittlement, loss of PASS.
7.	Failure detection method	Total loss of tension shown by monitoring system. Audio—visual.
8.	Corrective action	Initiate emergency shutdown procedures. Investigate failure before attempting to re-moor.

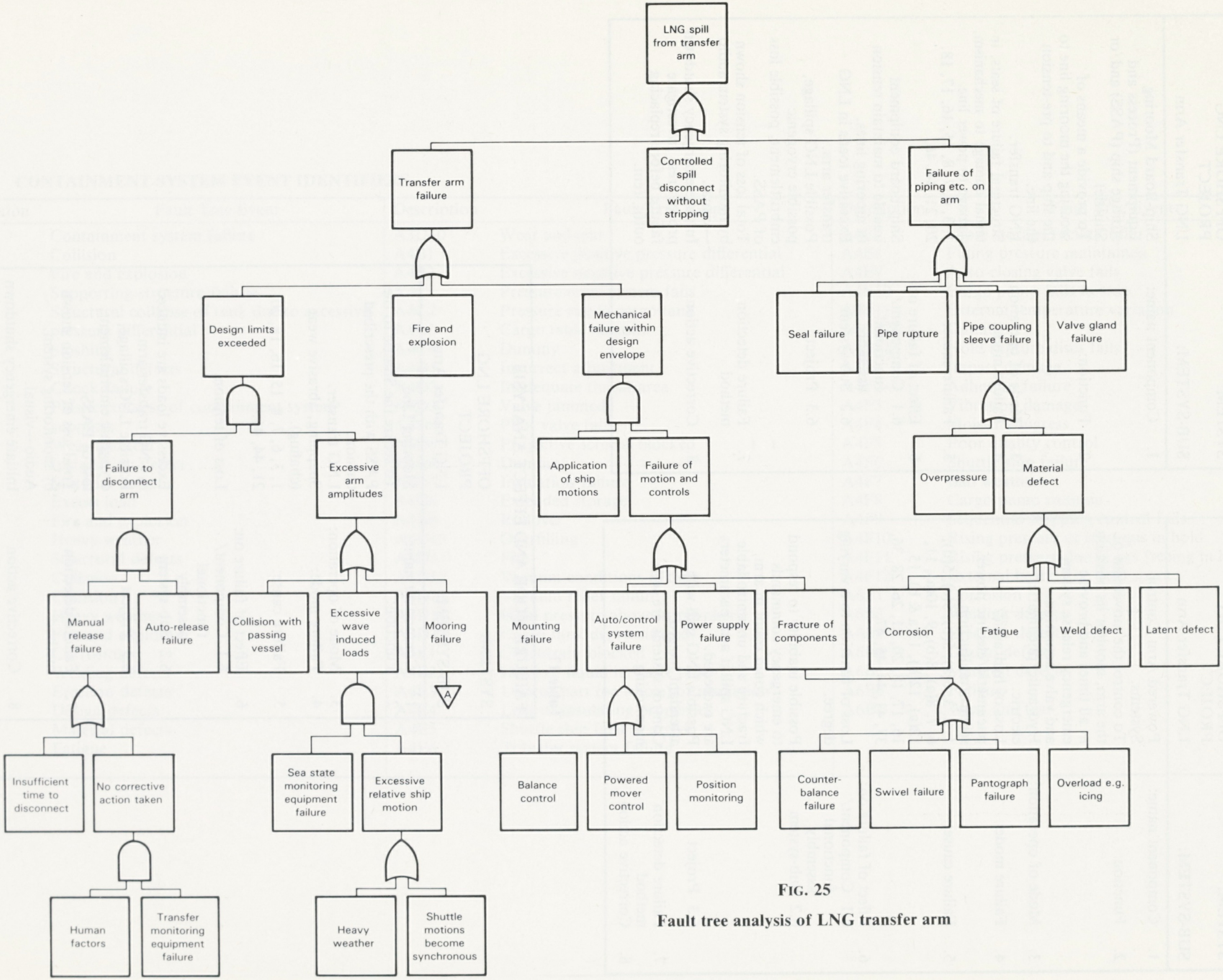


FIG. 25

Fault tree analysis of LNG transfer arm

31

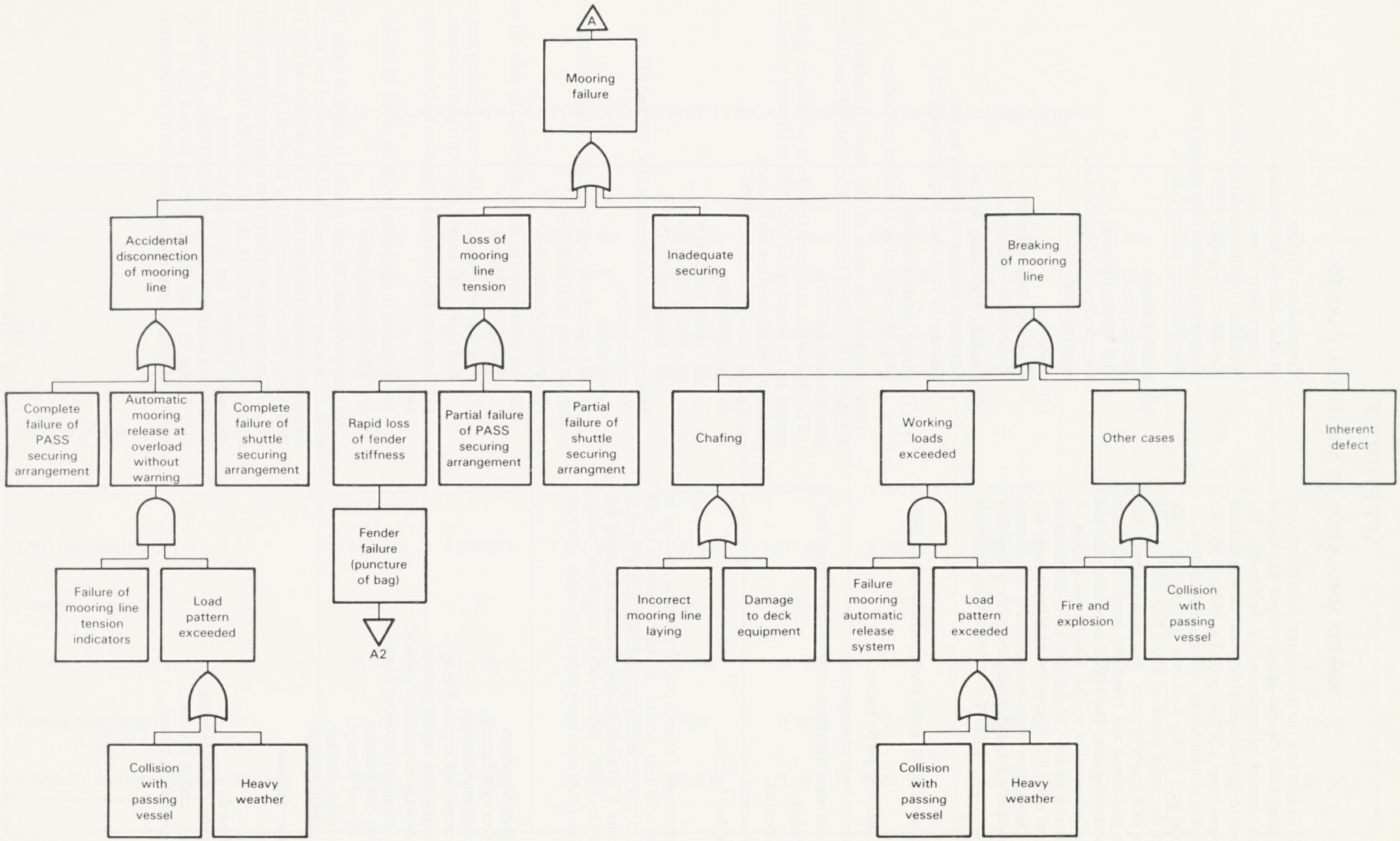


FIG. 26

Fault tree analysis of LNG transfer arm (cont.)

APPENDIX 5

MISSION SIMULATION OF ARCTIC LNG CARRIER

A very valuable insight into the operational performance of an Arctic ice-breaking LNG Carrier design project was viewed through a mission simulation conducted by the Society. The prime objective was to study the reliability and risks associated with operating a vessel over a 20 year period and also to provide comprehensive technical data for an economic evaluation.

The fundamental part of this work was the analysis of the specification and the main plans of the LNG carrier, and breaking it down into major systems. For each system, fault tree analysis was performed and reliability predictions made for sub-systems and top events. The MTBF were estimated and supplied as basic information to the mission simulation. A typical FTA is shown in Fig. 27 for the LNG containment system with a set of reliability figures for each basic event as a special example. The number of cut-sets found for this example was 147. An example of a detailed calculation of the probability of structural failure under specified unconfirmed ice loading is given in Appendix 6.

The simulation model used in this study considered two main aspects:

(1) The normal ship performance.

(2) Unreliability/risk consequences

Of special interest were the effects of (1) and (2) above on:

(a) LNG loaded.

(b) LNG delivered.

(c) Fuel consumed.

(d) Major safety hazards.

These were determined for each year for a total mission as specified, i.e. for a 20 year period. A central feature of the mission simulation was the ability to randomly generate event failures (see Section 9 Availability and Simulation) using the Monte Carlo method (48). Some of the simulator events selected from the fault tree analysis of the main systems included:

(1) **Ship's Hull Structure.**
Major fore-end damage.
Minor fore-end damage.
Major cargo tank region damage.
Minor cargo tank region damage.
Major damage to machinery space.
Minor damage to machinery space.
Major aft-end damage.
Minor aft-end damage.
Major rudder damage.
Minor rudder damage.

(2) **Machinery Failures**
Shafting.
Engine.
Switchboard.
Fresh water cooling system.
Sea water cooling system.
Power generation system.

(3) **Containment System.**
Primary barrier deformation.
Primary barrier fracture.
Secondary barrier/insulation panel fracture.
Gas detection system failure.
Temperature monitoring system failure.
Nitrogen purge system failure.

(4) **Outfit Failures.**
Ballast system.
Fuel system (heating).
Electrical power distribution.
Steering gear.

(5) **Crew.**
Crew incident—damage.
Crew illness—removal.

(6) **Loading/Unloading in Port.**
Structural damage to primary barrier.
Damage to cargo handling piping system.

(7) **Major Safety Hazards.**
Ship immobilised as a result of grounding.

Data provided for each of the above simulator events included the mean time between failure (MTBF) and the mean time to repair (MTTR).

The simulation calculated the effects of failures upon the normal performance of the ship. Where an event is randomly predicted, certain information is given,
e.g. Failure date: 353·9 day of 1986.
Sea/Ice condition:
i.e. (a) Open water (OW).
(b) First year ice (FY).
(c) Multi-year ice (MY).
Maximum allowable speed, in OW, FY and MY ice
Power reduction.
Repair times.

It should be noted that, built into and available to the mission simulation were, such details as:

(1) Route specification.

(2) Ice conditions for every month of the year for each section of the route.

(3) Horsepower requirements for ship breaking first year and multi-year ice and for open water resistance.

(4) Relationship between horsepower and fuel consumption.

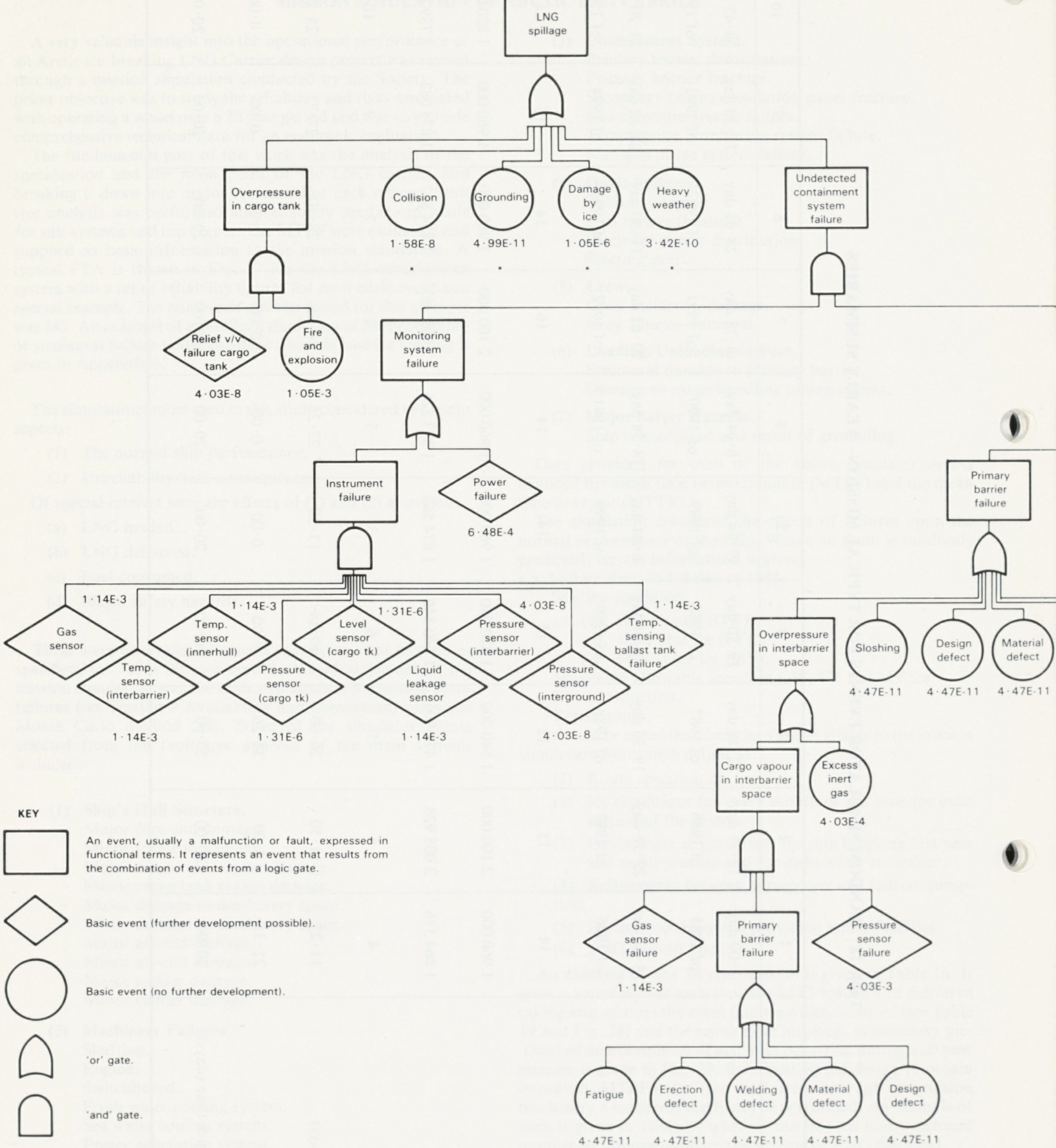
(5) Distance to shipyards providing repair facilities.

(6) LNG boil-off rates.

An example of one 20 year mission is given in Table 18. It gives a summary for each year the LNG loaded and delivered taking into account the event failures which occurred (see Table 19 and Fig. 28) and the repair time involved. A summary pie--chart of an example set of activities occurring during a 20 year mission is given in Fig. 29. By adjusting the design to obtain improved MTBF's for the hull structure and propulsion machinery a sensitivity study can be performed. An example of such is given in Table 20 where it can be seen how a reduced number of failures improve the volume of LNG delivered.

Table 18 RANDOM SIMULATOR EVENTS FOR TYPICAL MISSION—YEARLY SUMMARIES

	1	2	3	4	5	6	7	8	9	10
Start	1·00 day of 1985	18·71 day of 1986	22·18 day of 1987	19·50 day of 1988	17·74 day of 1989	6·04 day of 1990	8·78 day of 1991	23·61 day of 1992	11·30 day of 1993	24·42 day of 1994
End	18·71 day of 1986	22·18 day of 1987	19·50 day of 1988	17·74 day of 1989	6·04 day of 1990	8·78 day of 1991	23·61 day of 1992	11·30 day of 1993	24·42 day of 1994	23·20 day of 1995
Number of trips	14	15	12	13	14	14	16	14	15	14
LNG loaded (m^3)	1 960 000	2 100 000	1 540 000	1 820 000	1 960 000	1 960 000	2 100 000	1 960 000	1 960 000	1 820 000
LNG delivered (m^3)	1 864 576	2 008 928	1 471 906	1 740 540	1 874 567	1 873 526	2 009 165	1 874 847	1 874 083	1 739 859
Number of events	4	5	5	6	3	7	2	7	9	10
Total repair time (days)	11·25	11·50	26·00	40·34	13·50	27·25	4·75	20·50	27·75	25·25
Towing time (days)	21·31	0·00	34·26	0·00	0·00	0·00	0·00	0·00	0·00	0·00
Scheduled maintenance time (days)	20·00	20·00	20·00	20·00	20·00	20·00	20·00	20·00	20·00	20·00



KEY

An event, usually a malfunction or fault, expressed in functional terms. It represents an event that results from the combination of events from a logic gate.

Basic event (further development possible).

Basic event (no further development).

'or' gate.

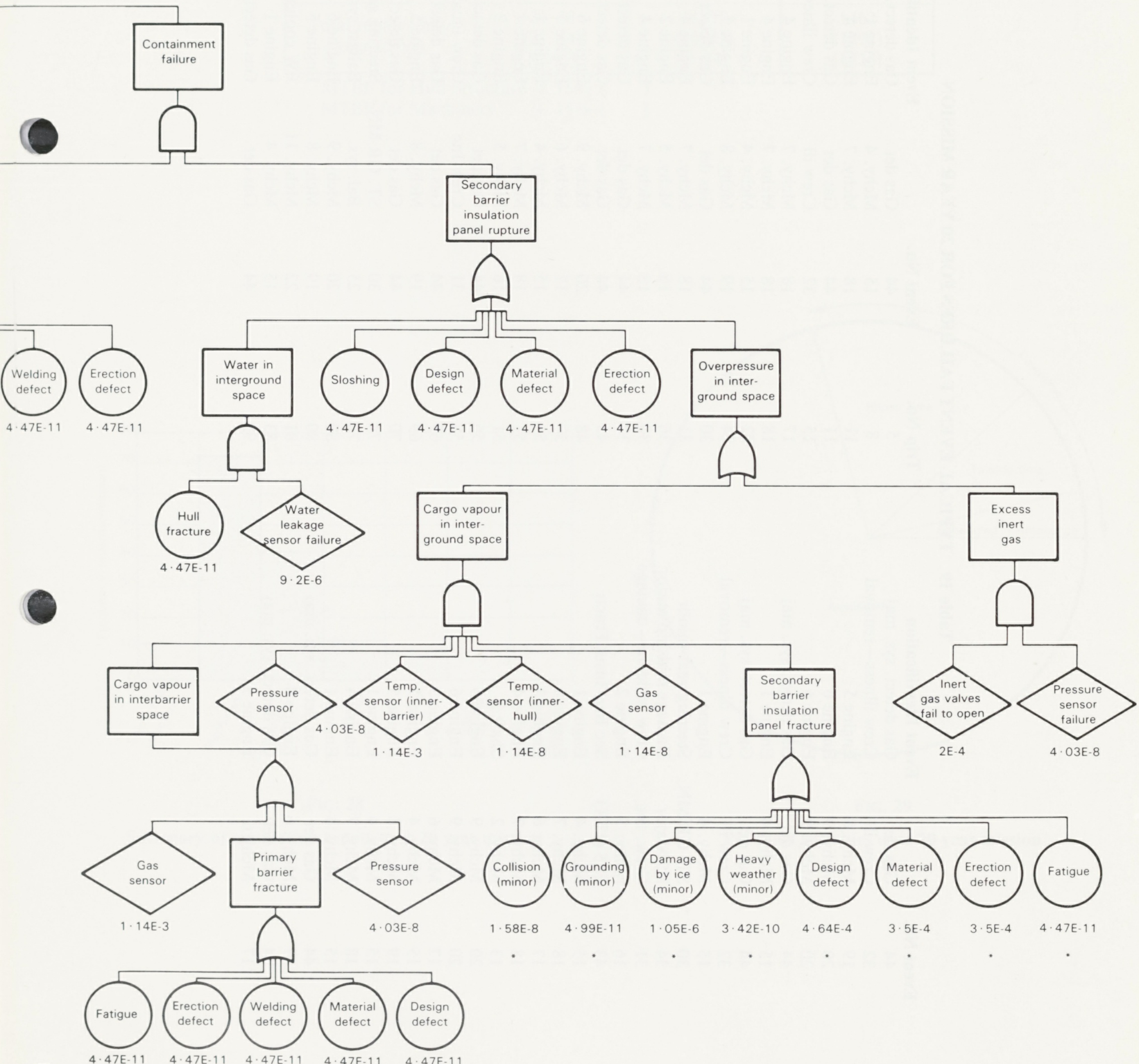
'and' gate.

Important footnote

The basic events and their frequencies are for illustrative purposes only. The numerical values should not be used unless specifically confirmed. Note that some values are for a ship operating in ice. Values marked '*' vary considerably with ship route and season.

FIG. 27

Fault tree analysis of L.N.G. containment system



Containment failure
Secondary barrier insulation panel rupture
Welding defect
4·47E-11
Erection defect
4·47E-11
Water in interground space
Sloshing
4·47E-11
Design defect
4·47E-11
Material defect
4·47E-11
Erection defect
4·47E-11
Overpressure in inter-ground space
Hull fracture
4·47E-11
Water leakage sensor failure
9·2E-6
Cargo vapour in inter-ground space
Excess inert gas
Cargo vapour in interbarrier space
Pressure sensor
4·03E-8
Temp. sensor (inner-barrier)
1·14E-3
Temp. sensor (inner-hull)
1·14E-8
Gas sensor
1·14E-8
Secondary barrier insulation panel fracture
Inert gas valves fail to open
2E-4
Pressure sensor failure
4·03E-8
Gas sensor
1·14E-3
Primary barrier fracture
Pressure sensor
4·03E-8
Collision (minor)
1·58E-8
Grounding (minor)
4·99E-11
Damage by ice (minor)
1·05E-6
Heavy weather (minor)
3·42E-10
Design defect
4·64E-4
Material defect
3·5E-4
Erection defect
3·5E-4
Fatigue
4·47E-11
Fatigue
4·47E-11
Erection defect
4·47E-11
Welding defect
4·47E-11
Material defect
4·47E-11
Design defect
4·47E-11

Table 19 TYPICAL EVENT FAILURES FOR 20 YEAR MISSION

Event No.	Event Identification		Trip No.	Event No.	Event Identification		Trip No.
44	Gas det	Gas detect. sys. maj	5	44	Gas det	Gas detect. sys. maj	100
32	Crew ill	Crew illness—removal	8	15	Mchy. 4	Engine 1	100
19	Mchy. 8	Engine 5	11	18	Mchy. 7	Engine 4	102
20	Mchy. 9	Engine 6	11	44	Gas det	Gas detect. sys. maj	104
20	Mchy. 9	Engine 6	15	32	Crew ill	Crew illness—removal	105
44	Gas det	Gas detect. sys. maj	17	18	Mchy. 7	Engine 4	107
15	Mchy. 4	Engine 1	18	18	Mchy. 7	Engine 4	110
44	Gas det	Gas detect. sys. maj	22	15	Mchy. 4	Engine 1	114
32	Crew ill	Crew illness—removal	24	19	Mchy. 8	Engine 5	115
15	Mchy. 4	Engine 1	30	44	Gas det	Gas detect. sys. maj	117
30	ST. GR MN	Steering gear minor	31	18	Mchy. 7	Engine 4	120
34	E5 Major	Damage midship major	36	16	Mchy. 5	Engine 2	121
31	Crew. Inc	Crew incident—damage	36	18	Mchy. 7	Engine 4	122
16	Mchy. 5	Engine 2	38	44	Gas det	Gas detect. sys. maj	123
43	E15 (1TK)	Sec Bar/Insul Fractr	45	44	Gas det	Gas detect. sys. maj	123
15	Mchy. 4	Engine 1	48	20	Mchy. 9	Engine 6	127
18	Mchy. 7	Engine 4	50	17	Mchy. 6	Engine 3	128
17	Mchy. 6	Engine 3	51	15	Mchy. 4	Engine 1	128
18	Mchy. 7	Engine 4	51	18	Mchy. 7	Engine 4	129
13	Mchy. 2	Shaft 2	51	16	Mchy. 5	Engine 2	135
20	Mchy. 9	Engine 6	56	44	Gas det	Gas detect. sys. maj	136
20	Mchy. 9	Engine 6	58	31	Crew Inc	Crew incident—damage	136
17	Mchy. 6	Engine 3	65	44	Gas det	Gas detect. sys. maj	138
15	Mchy. 4	Engine 1	69	19	Mchy. 8	Engine 5	139
19	Mchy. 8	Engine 5	70	44	Gas det	Gas detect. sys. maj	139
15	Mchy. 4	Engine 1	74	30	ST. GR MN	Steering gear minor	141
18	Mchy. 7	Engine 4	78	25	Bal. sys.	Ballast system	145
15	Mchy. 4	Engine 1	80	20	Mchy. 9	Engine 6	150
44	Gas det	Gas detect. sys. maj	80	19	Mchy. 8	Engine 5	151
17	Mchy. 6	Engine 3	81	22	Mchy. 11	FW cooling system	152
44	Gas det	Gas detect. sys. maj	83	15	Mchy. 4	Engine 1	152
17	Mchy 6	Engine 3	92	44	Gas det	Gas detect. sys. maj	152

Table 20 SIMULATION SENSITIVITY STUDY
3 × 20 YEAR MISSIONS WITH MTBF'S INCREASED BY 15%

	Mean	Standard deviation	Total over 60 years
LNG delivered/ year (m^3)	1815188 (1850506) [1866919]	185629 (172219) [130233]	109×10^6 (111×10^6) $[112 \times 10^6]$
Number of events/ year	5·98 (5·45) [5·22]	2·45 (2·35) [1·92]	359 (327) [313]
Total repair time/ year (days)	24·38 (21·54) [20·5]	11·35 (10·52) [8·78]	1462 (1292) [1230]

MTBF for Hull Structure + 15%:( )
MTBF for Machinery + 15%:[ ]

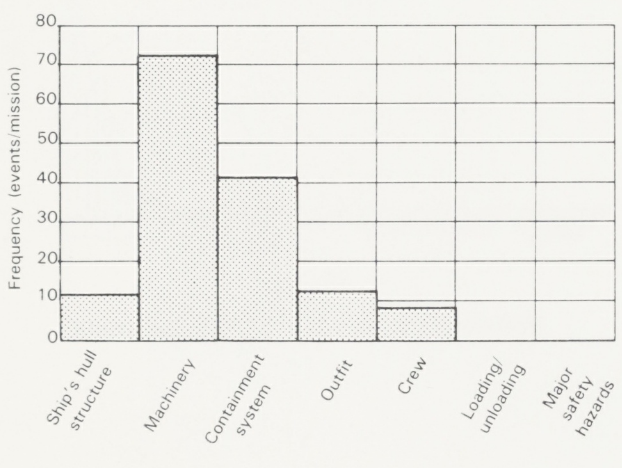


Fig. 28

Summary of simulation events over 20 year mission

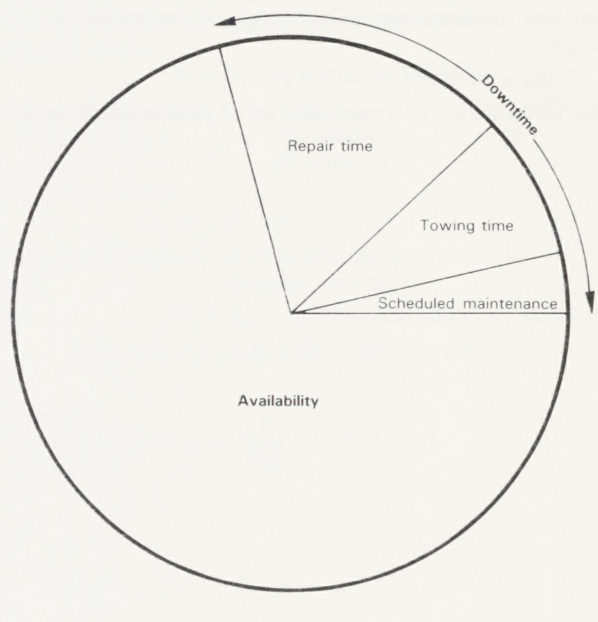


Fig. 29

Pie chart activities over 20 year mission

APPENDIX 6

STRUCTURAL RELIABILITY UNDER ICE LOADS

An analysis of the probability of failure of the ship structure in the fore-end and midship regions under various ice conditions has been made. This was studied by calculating the statistical variation of the applied ice pressure and the strength of the structure locally and also over a grillage structure.

Initially, a ship can make contact with the ice over a defined area. The crushing strength of the ice can then be assumed to respond to the confined compressive strength (f_c). As the contact area increases so the pressure required to crush the ice approaches the unconfined compressive strength (f_μ). In this case the overall hull pressure over the contact area will decrease.

By way of an example, let us consider the probability of local structural failure. It is assumed that the pressure on the hull will correspond to f_c.

For a sample of ice data from an Arctic region for first year (FY) ice and multi-year (MY) ice, a statistical analysis showed that the confined compressive strength (f_c) followed a normal distribution,

i.e. FY ice: $\mu_c = 183$ kgf/cm², $\sigma_c = 82$ kgf/cm²

MY ice: $\mu_c = 218$ kgf/cm², $\sigma_c = 45$ kgf/cm²

where μ_c = Mean of normal distribution

σ_c = Standard deviation of normal distribution.

Calculation of the hull strength was based upon rigid-plastic analysis assuming that no buckling would occur, i.e. ratio of stiffener spacing/plate thickness less than 25, and that failure would occur due to material yielding (σ_y) only. Failure due to shear was the dominant failure mode of the transverses and stringers:

i.e. Collapse pressure, $p_c = 7{\cdot}5\,\sigma_y$

An investigation of a particular set of yield strength data for steels suggested that the yield stress followed a normal distribution. For LT60 steels a mean of 40 kgf/mm² and a standard deviation of 1·7 kgf/mm² was adopted. Ignoring geometric variations, the normal strength distribution can then be found from:

$$f_s = \frac{1}{\sigma_s\sqrt{2\pi}} \exp\left[-\tfrac{1}{2}\left\{\frac{p_s-\mu_s}{\sigma_s}\right\}^2\right]$$

where σ_s = Standard distribution of strength distribution.

p_s = Collapse pressure.

μ_s = Mean of strength distribution.

Since f_s and the probability of pressure f_p are known, the structure will fail whenever $f_s < f_p$, i.e. when $(f_s - f_p) < 0$.

If f_s and f_p are normally distributed, it follows that $(f_s - f_p)$ will have a normal distribution.

$$\therefore \text{P [Failure]} = \text{P }[(f_s - f_p) < 0]$$

$$= \int_{-\infty}^{0} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\tfrac{1}{2}\left\{\frac{x-\mu}{\sigma}\right\}^2\right]dx.$$

For MY ice the parameters become:

$$\mu = (\mu_s - 218) \text{ kgf/cm}^2$$

$$\sigma = (\sigma_s^2 - 45^2)^{0\cdot5} \text{ kgf/cm}^2$$

The probability of failure, for an example of MY ice applied to structure in the midship region where $\mu_s = 310$ kgf/cm² and $\sigma_s = 13$ kgf/cm², was calculated as 0·0175 from standard tables for a solution of the above equation. It must be borne in mind that the risk of structural damage in ice to be used in the FTA depends also upon the probability that the ice loading conditions are encountered in service.

APPENDIX 7

PROBABILITY AND RISK OF SHIP COLLISION

Many of the marine safety problems centre around the risks from ship collision. The penetration of a cargo containment system for nuclear waste, LNG, harmful chemicals or breaching of a Ro-Ro ship pose everyday questions regarding safety.

The examples given using fault tree analysis identify the threats from collision.

From a distribution of the kinetic energy in the world fleet, it should be possible to determine the probability of penetration from:—

P [Penetration] = p[K.E.] × p [collision]

where p[K.E.] = probability of exceeding and meeting a kinetic energy value in world fleet

p[collision] = probability of colliding which will depend upon location.

An initial investigation for example gives a kinetic energy distribution as shown in Fig. 30. The cumulative distribution is given in Fig. 31. From an estimated kinetic energy value calculated to cause penetration it is then possible to calculate the probability of collision penetration as shown in the example.

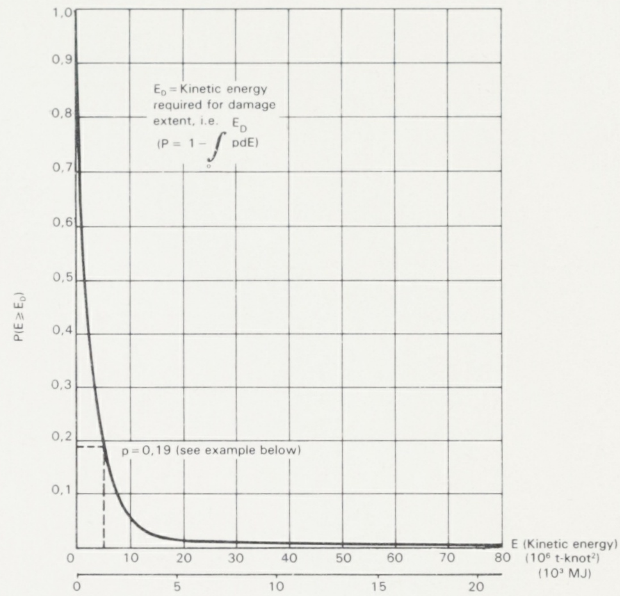


FIG. 31

Cumulative kinetic energy distribution of LR classed fleet

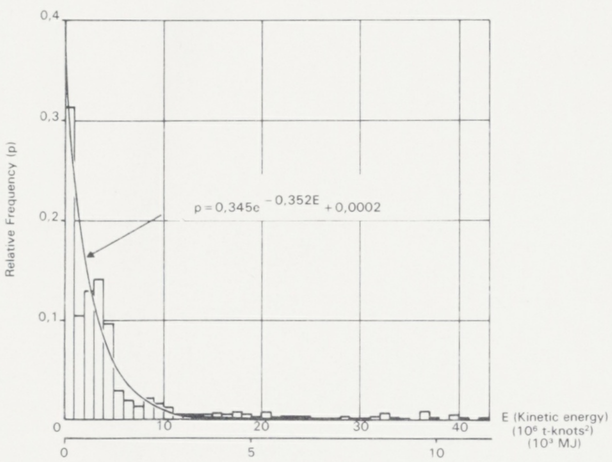


FIG. 30

Kinetic energy distribution of LR classed fleet

Example

From analysis of structure, energy required for given damaged extent,

$$E_D = 5 \times 10^6 \text{ t-knot}^2 \text{ (1333 MJ)}$$

Probability of experiencing a collision of at least this energy = Probability of collision × Probability of ship having KE of at least E_D,

i.e. $P_D = P_C \times P$

From Distribution P = 0,19 (corresponding to 5×10^6 t-knots² above)

$P_C = 3{,}5 \times 10^{-2}$ (typical value per ship year)

therefore $P_D = 6{,}65 \times 10^{-3}$ per ship year

or

Mean time between collision of energy E_D $= \dfrac{1}{P_D} = 150$ years

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Discussion

on the paper

RELIABILITY AND SAFETY ASSESSMENT METHODS FOR SHIPS AND OTHER INSTALLATIONS

by

Messrs. D. S. Aldwinckle and R. V. Pomeroy

Paper No. 4. Session 1982-83

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Discussion on the Paper

RELIABILITY AND SAFETY ASSESSMENT METHODS FOR SHIPS AND OTHER INSTALLATIONS

by

Messrs. D. S. Aldwinckle and R. V. Pomeroy

DISCUSSION

From Mr. B. Rapo:

The presentation we have just heard is very impressive as is the content of the Paper which reflects the accumulated experience of the Society in the field of safety assessments. As a man who has not been closely associated with this work my contribution will be mainly questions rather than comments:

The curve in Fig. 1 is intended to illustrate a growing number of accidents. However, it is my feeling that other curves could have been drawn, based on the same histogram, with a different end result and, perhaps, a better fit. Should I conclude that the curve shown was selected to increase our awareness of the problem?

In the final paragraph on page 1 it is stated that the Rules, Regulations, Codes of Practice and DCPD serve the industries well but that we should not become too complacent. The implication here is that something is missing. Is it the Authors contention that the existing standards, as represented by the Rules, require enhancement and, if yes, would this be in the form of a specific requirement for reliability analysis to be carried out? How much would the safety of a ship or installation be enhanced if such a requirement was instigated?

The method as presented appears to comprise three fundamental stages:

(a) Setting assumptions.
(b) Application of the mathematical theory of reliability.
(c) Interpretation of results.

It appears to me that the most controversial phase is likely to be the interpretation of results. Does it follow that an engineering solution having a probability of failure of 10^{-7} is necessarily several times better than an alternative solution with a failure probability of 10^{-6}? If the former solution involves a greater cost, say 10%, it is my guess that industry would not be enthusiastic to adopt it. After all, many of us do not go to the expense of fitting fire alarms in our houses, not because we doubt their value in enhancing safety, but because we are not confident that the additional cost would be justified.

The point I want to make is that in many circumstances the trade off between improved safety and the added cost required to provide it, could be considered a matter of commercial judgement and so, perhaps, not one in which the Society's intervention is appropriate.

There is another point which I want to raise but which quite obviously has no direct relevance to either the Authors or their presentation. Risk analysis can be used and manipulated to produce results which may be considered politically opportune. In this context the method can seem to lack objectivity. Let us remember the movements for and against nuclear power stations where both sides are able to produce risk analysis results apparently supporting their directly opposing views. Can the Authors suggest ways in which complete objectivity could be seen to be achieved?

Re. Fig. 29 it is noted that a substantial portion of the pie-chart indicating downtime is designating TOWING TIME. Is the towage of an LNG carrier of the size envisaged, in multi-year ice conditions, a feasible proposition?

From Mr. G. P. Smedley:

By tradition the safety of a structure, machine or pressurised container has been determined by a safety assessment covering four principal areas. The first concerns the evaluation of the loadings and the associated general stresses and local stresses at attachments and discontinuities. These had to be below levels determined from appropriate failure criteria taking account of uncertainties and the hazards posed by the item. The second area relates to good workmanship in accordance with defined standards and proven by quality assurance. The third concerns precautions against specific environmental conditions (e.g. corrosion, low temperature), possible overload, and safeguards of personnel and property in the event of failure. The final consideration is the frequency and extent of in-service inspections. Table 4 neglects inferior or inadequate workmanship as hazardous sources. Experience shows quite clearly that these have been responsible for many failures in service. Unless these areas are properly defined and this is the job of the designer, the further analyses described in the paper will count for nothing.

Catastrophic failures must be priority targets for action. Most stem from poor design, including incorrect selection of materials, bad workmanship, inadequate proving of the construction, neglect in service (or to take effective action as a consequence of earlier accidents to similar engineering items) and mal-operation. All too often inadequate or no action is taken notwithstanding a clearly defined cause or causes.

The casualty rates quoted in Table I are unacceptably high and are about an order of magnitude above the norm for general merchant ships. As shown in the attached notes which I prepared on offshore installations, the casualty rates for mobile units are also high (over 1 loss/100 rig years) while those for fixed structures taken over the recent decade are remarkably good (less than 1 in 10,000 platform years). While the current revision of the Rules for Mobile Drilling Units will reduce casualties, benefit for jack-up rigs has come from an unusual source. A main cause of casualties to these rigs has been storms during tows. Provision of special ships to transport jack-up rigs as deck cargo is eliminating this hazard.

Where casualty rates exceed 1 in 1000 unit years and are serious in nature, investigation is desirable to establish the cause or causes. Once established future rates must be studied to confirm the effectiveness of the actions. Some years ago TRO

provided regularly to PAMETRADA casualty data for their designs of geared steam turbines, and those of other types. I recall two distinct cases, bent turbine rotors and machining type failures of turbine thrust collars. The records confirmed the benefits in the former case of spring backed glands; and in the latter, the elimination of certain additives to the lub-oil and of rotor steels containing chromium were effective cures. Viewed in retrospect I doubt if either type of casualty could have been predicted by fault analyses at the design stage. Thus the recording of casualties is a vital service.

As indicated in Fig. 2 of the paper, human error plays a major part in casualties. There is controversy as to what extent it can be handled in probability estimates at nodes and gates in fault and event trees. Could the Authors express their opinions on the matter?

From experience of in-depth analyses of installed plant and equipment of offshore platforms, these were time consuming even for a trained team. Figures of 9 to 12 months have been quoted to me. It was often found that the actual installations departed significantly from the drawings. All departures had to be determined before proper analyses could be performed by the team. Once the installations had been modified to take account of the findings, regular audits were performed to confirm continued compliance with the established requirements and conditions. Nevertheless, the Operators of the installations considered that the tasks had been essential and highly informative to their practices and the safety of the units. This confirms the conclusions of the Authors that the Society must strengthen its efforts in all sections covered by the paper. They are to be congratulated for a well timed and interesting presentation.

Supplement to Mr. G. P. Smedley's Contribution.

OFFSHORE INSTALLATIONS

A REVIEW OF SOME CASUALTY DATA

1. INTRODUCTION

Because of the hazards of the sea, safety, risk and reliability have special meanings to those concerned with ships and offshore installations. Each interested party has particular concerns about risks. Some of these are as follows:

(a) COMMERCIAL CONCERNS (Banks; Governments; Trusts; Companies; Individuals).

Risk of loss of capital or inadequate return on the investment arising from:

Over-estimate of the reservoir or the amount of oil or gas which can be recovered from the reservoir.

Delay in completion of the installation.

Loss or damage to the installation (i.e. prolonged loss of production or excessive cumulative delays to production).

Greatly increased costs of replacements, repairs, additional inspections, etc.

(b) OWNER; OPERATOR

In addition to the foregoing, the following are extra problems:

Major delay in exploration.

Sudden cut-off of feedstocks to shore based process plants.

Failure to meet requirements of contracts to third parties.

Infringements of laws on safety and anti-pollution.

Casualties to work force; possible loss of vital skills; claims for compensation.

Adverse publicity reflecting over the whole of the businesss.

(c) LEGISLATING AUTHORITIES (Government Departments)

Impact on requirements for safety and avoidance of pollution, (i.e. protection of persons and property).

Protection of supplies of oil and gas; Concern about balance of payments and revenue.

(d) INSURANCE COMPANIES

High claims associated with loss or serious accident on or to an installation.

(e) WORKFORCE — UNIONS

Possible inadequacies in workplace safety, job safety, operational safety and provision for survival in the event of an accident.

2. STRUCTURES

It goes without saying that the total loss of a structure or even major damage, is of principal concern to all parties. The structures may be designed for the purposes of exploration or exploitation of oil and gas from beneath the sea bed, in widely differing water depths and environmental conditions.

Early in 1981, the National Research Council, Washington, published a Report on "Safety and Offshore Oil".[1] A summary of statistics contained in the Report, and relating to casualties to mobile drilling rigs and fixed steel platforms is given in Table 1. For purposes of comparison some data are included on merchant ships. The NRC Report treats structural failures, and fires and explosions in separate sections. Table 1 also gives casualty data derived from another source.[2] These represent the overall picture.

Points of interest are as follows:

FIXED STEEL PLATFORMS

The casualty data concern fixed steel platforms in the Northern Gulf of Mexico. In the late 1940's platforms were of simple design and construction, and were in shallow water (up to 7 m). Thereafter there was a rapid build up of platforms in this area and in increasing water depths. By 1979 some 2,420 platforms were in place, the latest being in water depths of 270 to 330 m. A principal hazard to the platforms is hurricane storms when wave heights can be as great as in most other sea areas. It was not until about 1964 that researches and computer techniques permitted a proper method for the design of welded tubular steel structures. Nevertheless, the total losses over the 30 year period have been low (about 40 platforms). 50% of these were small structures in water depths of less than 19 m. Three casualties occurred by collisions with ships and rigs during storms. Over the period 1969-79 only two losses were reported, the cumulative platforms years being some 20,300. This is a remarkably good record.

TABLE I

CASUALTY STATISTICS

MOBILE OFFSHORE UNITS (1955/80)

(Environmental or Operational Overload)

UNIT	Years to Loss	Loss/100 years	Years to Loss + Major Damage ø	L + D/100 years
JACK-UP's	78 (52)	1.28 (1.93)	39	2.56
SEMI-SUB's	184 (156)	0.54 (0.64)	54	1.85
(PENTAGONNE)°	60	1.7	—	—
DRILL SHIPS	262 (164)	0.38 (0.61)	87	1.15
DRILL BARGES	—	—	—	—
FIXED PLATFORMS*	875	0.11	—	—
(1964-79)	2,000	0.05	—	—
(1969-79)	10,000	0.0001	—	—
MERCHANTSHIPS ▿ (Average)	—330	0.3	—	
LIBERTY SHIPS ▵ (original)	—	—	24	4.2
IMPROVED DESIGN	—	—	185	0.54
T2 TANKERS (original) ▵	—	—	53	1.9
WITH RIVETED STRAPS ▵	—	—	82	1.2

* Gulf of Mexico

° To loss of "Alexander L. Kielland"

ø Major damage—Repairs costing over $500,000

▵ Class I brittle fractures—endangered the vessel or resulted in its loss

▿ All causes of loss

( ) Data in Offshore Rig Data Services, May 1979

In general cumulative wave loading is much less serious in the Gulf of Mexico than in more hostile sea areas such as the North Sea. Here fatigue cracking of tubular connections poses greater problems. Nevertheless, the indications are that a measure of redundancy in the design, the high standards of construction, and periodical inspection (although somewhat limited) will ensure a low risk of total loss compared with other types of marine structures.

Tanker loading units of buoy or spar types are also fixed structures. These are relatively new features in the offshore scene. The indications are that buoy types are more reliable than articulated spar types. However, further service is necessary to indicate the likely performance.

MOBILE DRILLING UNITS

(a) Drilling ships and barges were combined for the purposes of the assessment of casualty rates. The overall rate of loss is the lowest for the principal types of mobiles. In fact the majority of the casualties in this group of mobiles have been to the barges. The self-propelled drilling ship with its ship shape hull has a very good record. A ship is less prone to storm damage; it does not require towing from one location to another.

In September 1981 it was reported that the drilling ship "Petromar V" sank in the Natuna Sea off Indonesia after a massive gas blow-out which impregnated the sea and gave rise to loss of buoyancy. If this were the case, the event would be of such low probability as to be in the class of an "act of God".

(b) Semi-submersibles appear to have a lower casualty rate up to the end of 1979 than records showed up to 1974.[3] This may be related to the increased number in service and the greater total rig-years. However, the casualties show that these mobiles are prone to storm damage and structural cracking such as fatigue failure. These emphasise the need for greater attention to weld detail in design and inspection, and strict operation in accordance with the "Operations Manual" where such rigs are designed for specific headings in storms.

(c) Jack-up rigs are the most prone to loss and serious damage. Certainly the casualty rates are significant. While these rates are of the order of those for brittle fractures to the early mass-produced, all welded Liberty Ships and T2 tankers of World War II, they are associated with several distinct causes. Table II gives the breakdowns of causes of losses and serious damage to mobile drilling rigs. Blowouts, storms, especially during tows, and collapse when on station constitute the main causes for accident to jack-ups. Collapses may arise from soil failures, jacking accidents and structural fracture of the supports.

TABLE II

CAUSES OF LOSSES & SERIOUS DAMAGE

(Mobile Drilling Units)

LOSS	J.U.	Semi-sub.	Drillship & Drill Barge	TOTAL
Blowout	9	2	1	12
Tow	(9)	(1)	—	(10)
Storm	(6)	(3)	3	(12)
Collapse etc. on site (Soil failure etc.)	7	—	—	7
TOTAL	31	6	4	41
DAMAGE				
Blowout	4	3	3	10
Tow	(13)	(2)	1	(16)
Storm	(5)	—	(1)	(6)
Collapse etc.	7	—	—	7
Fire (Expl.)	2	—	1	3
TOTAL	31	5	6	42
PARTIALLY OR EVENTUALLY SALVAGED				
Tow	1	—	—	1
Collapse	—	—	—	0
(Soil failure)	2	—	—	2
TOTAL	3	—	—	3
GRAND TOTAL (Total Rig Years)	65 (2332)	11 (921)	10 (1048)	86 (4301)
Blowout	13	5	4	22
Tow	23	3	1	27
Storm	11	3	4	26
Collapse etc.	16	—	—	16
Fire (Expl.)	2	—	1	3

Since some of these causes are event dependent rather than time dependent, it can be argued that casualty rates based on rig-years of service, are not the best method of presentation. Unfortunately the data are insufficient to permit alternative presentations. However, the casualty rates are satisfactory for the purposes of comparison. A weakness is the influence of periods of low demands for the services of rigs. For example, some authorities felt that reduced incidences during the period 1976 to 1979 was indicative of a "learning curve". A recession in the rig market is more likely because when the tide turned in 1979 casualties showed a marked upward turn. Information for 1980 shows that it was the worst year on record for casualties to mobiles. There were 22 incidences with at least six total losses. Eighteen of the casualties involved jack-ups with at least four total losses. In 1979, 229 jack-ups were in service. In early 1980 the number had increased to 237 with 120 new rigs in various stages of construction. Rig contractors reported that the upturn in business and new construction stretched manning requirements and necessitated dilution by less experienced crew members. This, and a particularly severe hurricane in the Gulf of Mexico, may have had some influence on casualties for 1980. Yet, even allowing for these circumstances, the incidences remained significantly above the norm. It is evident that the average casualty rates should be increased by a factor of about 1.4 to predict the probable incidences in a year of peak demand.

Over the whole period under consideration, there have been three cases in which rigs suffered two casualties of the types forming the basis of the statistics. Clearly the first incidence cannot result in a loss; the second may be a loss or result in serious damage (i.e. over $500,000). All three cases were jack-up rigs. This is to be expected. However, even if the casualty rates were based on data including 1980, the factor for utilisation has to bę taken into account, to predict the three dual incidences.

3. CAN CASUALTIES BE REDUCED TO JACK-UPS?

In addition to the problems referred to in Section 2, there is also some concern in the U.S.A. about mud slides during storms of mat-type jack-ups. While such incident has not resulted in a casualty, it is another issue which falls within the realm of soil mechanics. The trend, especially in the U.S.A., is for owners of jack-ups to gain some knowledge of soils before placing a jack-up, by obtaining cores from the sea bed in the particular location. This should reduce the risk of loss of leg support during jacking-up or after this operation has been completed.

At present there appears little hope of removing the legs of modern jack-ups before a tow. Greater attention is being given therefore to routing and weather forecasting for tows. For the smaller jack-ups preference is being given to barge towing.

In other respects, the calibre of the crew and the recommendations of the Report of the inquiry into the loss of "Sea Gem" are the other important issues with respect to safety.

Although it is not confined to jack-ups there is growing concern, especially in the congested waters of the Gulf of Mexico, about the increasing risk of collision between rigs, a rig and vessel, or one of these floating units and a fixed structure. This matter is receiving the attention of the U.S Coast Guard.

4. FINANCIAL VALUE OF RIG LOSSES

The Author has no first-hand knowledge of this subject. In March 1981 it was reported in the technical press[4] that the monetary loss arising from 140 mobile rig mishaps over 26 years totalled over $744 million. This total excluded some six cases for which damages had not been assessed at the time. Some 50% of this sum had been incurred in the 1979-80 period. This reflects the concern expressed in Lloyd's List in mid-September, 1981, at the rock bottom rates quoted by some sections of the insurance market for coverage of risks to mobile offshore units.

5. SAFETY OF PERSONNEL

This subject covers four distinct areas:

Work place safety.
Job safety.
Operational safety.
Survival.

It is usual to make an initial assessment of these matters by consideration of injuries and fatalities with respect to those on fixed and mobile offshore structures (including a breakdown into broad job category). Survival is important because it concerns "falls into the sea" in addition to escape and rescue in an overall emergency.

Both the U.S. Report and that of the Burgoyne Committee[5] expressed concern about the hazards of working on the drill floor. The former quotes a survey of accidents to crews on jack-up drilling rigs. The recorded information can be expressed as follows:

TABLE III

Relative Injuries to Personnel on Jack-up's

Occupation	*Injuries/man year*
Roustabout	1.65
Roughneck	1.31
Derrickman	1.29
Drillers	0.88
Crew	0.81

Somewhat surprising findings of the studies of injuries and fatalities to personnel offshore were as follows:

76.5% injuries occurred to employees with less than one year in the job. 55% had less than six months in the job.

Most accidents occurred in the first to fourth hour of duty.

For drill floor personnel "caught between" was the most common type of accident. Back injury was also frequent.

For other personnel, "struck by" and "fall" were highest incidences. The Burgoyne Report indicates that these two kinds of accidents accounted for 35% recorded accidents and dangerous occurrences of all types on offshore installations.

Over 90% of accidents arise from action or inaction of another person.

Absence of protective equipment concerned about 10% of the cases.

The U.K. Department of Energy Brown Book (published annually) reviews statistics of accidents. The 1979 edition reported that, taken overall, an offshore worker is about twice as likely to have an accident as a person engaged in general manufacturing industry, and about half as likely as a miner.Neglecting minor accidents offshore (for which there is no breakdown) there was a significant reduction over a five year period in fatalities and serious accidents per 1,000 personnel. Excluding diving; helicopter and domestic categories, drilling, boats, cranes and construction-maintenance, are areas where improvements might be effected to reduce injuries to personnel.

From the U.S.A. there is evidence to indicate that on installations owned by oil companies, contractors' men were over six times more prone to accident than the staff of the operator. This reflects greater experience offshore for representatives of oil companies, and differences in job type.

With reference to means of reducing accidents, there are three main approaches:

Engineering—This offers some scope by easing or reducing the more hazardous tasks involved in drilling and some other areas.

Education & Training—These are so important that some Governments have already sought the assistance of industry.

Enforcement (Legislation)—The consensus of opinion is that increased legislation is unlikely to result in significant gains. The other two approaches offer the true scope on overall improvement in safety.

The U.S. Coast Guard have analysed the records of survival with respect to "man overboard" and "abandon ship or rig" incidences. The chances of survival from a rig fixed on station are significantly higher than for a ship because the latter has frequently been underway at the time of the accident. Moreover, rescue is generally more rapid for a rig or platform incident because of the location of the standby vessel, and helicopter assistance. Life jackets or survival suits also have increased markedly the chances of survival and rescue. Modern capsule and other life saving devices are shown to advantage in an emergency.

Escape and survival are such that there is no room for complacency. There are lessons to be learned from the tragedy of "Alexander L. Kielland". These apply to escape as much as survival and rescue from the sea. Both engineering and education are key issues.

The relatively rapid turnover of personnel poses problems to Contractors. Many men do not settle to employment offshore or are attracted by the glamour which soon wears off. The situation is aggravated by the variable demand for services that is inherent to the business of drilling, the installation phase of fixed platforms, and modifications, maintenance and repair to such platforms. Thus the changing work force increases the responsibilities of supervisors.

6. CRANE ACCIDENTS

For several years crane accidents have been cause for concern. The U.K. Department of Energy reported that these mishaps made up 17% of all accidents reported on offshore installations (*see* Appendix 15 of Reference 5). Some arose from faulty design, construction and equipment. Most were the result of improper procedures and operator errors. Design aspects of pedestals, slewing rings and their bolted connections have already been resolved. The issues of outstanding importance are:

(a) The avoidance of overload.

(b) Ensure good communications and good visibility for operators.

(c) Avoid lifting and swinging loads over personnel.

(d) Consider heave compensation to reduce dynamic loading.

(e) Check that the equipment is efficiently maintained and that slings and nets are adequate for the job.

(f) Train crane operators to recognised standards.

Crane accidents do not relate solely to operating mobiles and platforms. Many accidents have occurred during the installation phase of a fixed platform when contractors have been lifting piles, topside equipment, and the plant and equipment essential to the hook-up. The listed issues are of equal importance during the installation phase, in the interests of the avoidance of injuries to personnel and serious damage to the structure and essential equipment.

7. PLANT AND EQUIPMENT

Fires and explosions arising from accidents to plant and the use of certain types of equipment, are of primary concern on oil and gas installations. The recognition of hazardous areas and the requirements for safety therein have reduced greatly the risk of major fires. Nevertheless, both the Reports of NRC and the Burgoyne Committee expressed concern about incidences of fires. NRC quoted 270 fires and explosions on installations in the Gulf of Mexico. 261 were on fixed platforms, and 231 of these occurred during production. Nearly one third were associated with process equipment and glycol systems.

NRC drew attention to the disparity in incidences of occurrence on North Sea installations and those in the Gulf of Mexico. Thus:

Rate of occurrence of fires and explosions.

North Sea (Norway): One event in 0.76 complex-years.

U.S.A.: One event in 49 complex-years.

The difference which is nearly two orders of magnitude is unlikely to stem from the reduction in hazard from an escape or

build up of gas on the "open" type of installation in the Gulf of Mexico. Norway and U.K. record all types of fires and explosions on mobiles and fixed platforms, including those which occurred during the installation of a platform. Some 70% of the cases in Norwegian waters occurred during this phase. It is also probable that few Norwegian platforms (about one hundredth of those in the Gulf of Mexico) and the marked differences of size, manning and complexity, biased the statistic.

The Burgoyne Report noted 100 explosions and fires on U.K. installations in a six year period. Most of the fires were minor and arose from welding and cutting, electrical fault and cooking and domestic functions. In effect a significant proportion arose from human activities which did not involve process plant. For example, 34% of the incidences were caused by welding and flame cutting. All of these could have been avoided by taking simple precautions.

The 100 incidences over the stated period would give a statistic for U.K. installations of about one case in four complex-years. This value, intermediate between the statistics for Norway and U.S.A., has a bias because of the number of smaller and simpler platforms in the Southern Gas Field.

Clearly any possible source of ignition is critical and precautions must be taken to reduce the minor incidences. An important observation from the North Sea experience is that fires have been contained and justify the standards of structural fire protection and the extensive fire fighting equipment.

The Burgoyne Committee quoted the records of Lloyd's Register which showed that 17 cases of damage to about 60 installations in six years involved items of plant such as storage tanks, piping and gas turbines. The Committee recommended that important systems on installations should be the subject of hazard analyses similar to those effected for shore based chemical plants. A number of oil companies have already undertaken such analyses and audits. These have been costly and time-consuming, and have been updated to cover all modifications and additions. While these actions have taken some of the bugs out of system, the avoidance of accidents to plants still depends mainly on the vigilance of those who work the plants.

8. COMMENTS

Considered overall the record of fixed platform installations compares favourably with those of shore based industries. In hostile waters fatigue of welded tubular structures will pose some problems pending the results of researches on matters such as the true influence of section thickness. However, the designs of the structures and the periodical inspections are such that the risk of collapse is very low.

Principal concerns for structures relate to certain types of mobiles. The jack-up type remains the most vulnerable to loss and serious damage. The very nature of jack-ups introduces risks over and above those for semi-submersibles and drill ships. With increasing numbers of jack-ups in service, every precaution is necessary to avoid casualties during tow, when jacking-up and down, and over the period when the barge is in the elevated position on station. For these mobiles and semi-submersibles greater attention must be given to ensure that operation is in accordance with the design and as set out in the operation manual.

Efforts must also be increased to prevent the mischief of fatigue.

Action is in hand to reduce, so far as possible, accidents arising from the design and operation of the various types of plant and equipment. The causes of injuries and fatalities are also under review. Training, education and supervision offer scope for the avoidance of some of the job related incidences.

Pipelines, risers and incidences of pollution are beyond the scope of these notes. Notwithstanding provision to deal with spills, the record of the offshore industry is good. It has been far more vigilant than many other users of the sea, directly or indirectly, and has contributed greatly to the protection of marine life.

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From Mr. C. M. R. Wills:

I would like to congratulate the authors on their concise review of basic risk and reliability analysis methods and on the series of interesting examples given in the appendices. In particular, I would like to commend them on the diplomatic manner of discussing the future influences of these methods on the Society's procedures for the assessment and maintenance of safety standards which is perhaps more interesting in its implied rather than directly stated conclusions. I refer, in fact, to the implications with respect to our normal classification activities as opposed to those concerned specifically with special purpose, high risk or unconventional designs. This, I believe, will represent the future central issue with respect to risk and reliability in L.R.

In the past the approval of a Classification Society, L.R. in particular, has held a privileged status as being virtually unquestionably accepted as representative of satisfactory standards of safety and reliability. Recent trends, however, indicate that this is increasingly unlikely to be the case in the future. We have over the past few years experienced a growing tendency for our Rules and Survey Procedures to come under detailed technical examination at courts of enquiry and to receive an increasing level of technical criticism in the press. The evolution of our Rules and Procedures, based as they are on a wealth of sound engineering experience and feedback accumulated over many years, makes it difficult to quantitatively substantiate the imbedded safety and reliability standards under this type of criticism in other than a subjective manner. An approach that provides a quantitative basis for the assessment of these standards and their rational substantiation under external criticism must prove of significant benefit to the Society and the marine community in general.

I would like to make one further comment with respect to the identification of target reliability levels. I agree that, in principal, it is relatively straightforward to determine acceptable risk criteria by comparison with quantified risks to life and property currently accepted by the community at large, as illustrated in the paper. However, the task of translating such criteria into target reliabilities for the engineering systems subject to classification approval should not be underestimated.

The overall acceptable risk criteria must include all possible contributing factors from both classification and non-classification areas. In order to determine target reliabilities for classification items, it is first necessary to quantify the risk contribution from all other factors including any interaction effects. This will extend the

Society's activities, although not necessarily its responsibilities, into areas traditionally considered outside our terms of reference. In particular such aspects as operational procedures and human fallibility, which represent a significant contribution to overall risk, will need to be considered.

From Mr. G. J. Talbot:

From the analysis aspect some of the commercially available P.M. systems now being installed with on board training come very close to what I would consider desirable. Such schemes appear to have a more practical approach than either condition monitoring or real time data logging. They would appear to offer Classification some greater flexibility. They offer a standard system for analysis and the option of a limited amount of narrative.

In reading the paper I ask myself if a mission simulation would prevent or minimise further the type of accidents shown in Table II. One should never be complacent regarding the loss of life or limb but I would draw attention to the L.R. casualty returns for the world classed fleet for 1981, distributed last week, which shows loss of life for all ships including tankers for the years 1978 to 1981, and shown in column 6 of Table II. The inference which can be drawn is that tanker casualties are not exceptional and probably are a great deal better than many other ship types.

It is interesting to note from Fig. 8, page 11 that individual risks of the order of 10^{-6} and less are considered trivial and no action is required, whereas 10^{-5} is considered a high risk. Water transport is noted as lying mid-way between these figures. The figures are so miniscule that it is difficult to comprehend their practical application.

Turning to Appendix 2 and my reference to feedback reflecting the total system. You will note from Figs. 12 and 13 on page 17, that defective components being reported by L.R. Surveyors for medium and slow speed engines contain similar defective components. Turning to Fig. 14 on page 19 data supplied by an Owner shows the fuel system to be responsible for more than 50% of all defects. This latter data can be substantiated by Owners data available in TRO which show fuel systems account for 30% of all recorded main engine defects. A further source from Japan shows that fuel systems figure prominently in the top three components failing in 10 different types of marine diesel engines.

The words reliability and safety in the title of this paper have arisen on numerous occasions in TRO since it was introduced as part of the Society's current policy. It is timely that the Technical Association have brought this important paper before us this evening and the co-authors are to be congratulated in placing before us their ideas and showing some examples of how theory might be applied in practice. It is very much a developing discipline and I suggest the benefits will come in the long term.

Time has much to do with the subject; apart from the time element in events and failures the paper looks beyond the moment, it has to do with historic data and also looks to the future. It has the ingredients to change the patterns of survey work, it suggests moves away from set time periods for periodical surveys and allows opportunity to discriminate between Owners based on their choice of design and installation.

It is difficult to envisage the extent to which such techniques will be applied. In TRO we see "risk and reliability" as a long term project starting with major components and systems, ultimately progressing to the level of detail considered to be required.

I would strongly endorse the authors comments on feedback, but the feedback must reflect the operation of the total system and not just the Classification requirements as I will try to indicate.

A case has been made for collecting separate data from individual Owners and TRO do have several Owners contributing data. Ideally these should be Owners to whom we have relatively easy access. In the past their aid has been offered willingly but many are today either non-existent or reduced to few operating units with reduced manning levels. Data from such schemes, welcome as it is differs in content and requires different analysis techniques.

Fig. 17, page 19 giving incident rate per year for main boilers show peaks coinciding with the survey periods occurring at alternate years. Similar peaks can be seen for other surveys and indicates higher activity levels at survey periods as required by the Rules.

Current TRO feedback from the Classification reports show the efficacy or otherwise of the Rules and is quite proper. The examples to which I have drawn attention show that equally, other components affect reliability and cannot be ignored if risk, reliability and safety are to be meaningfully assessed.

I am surprised by the figures suggested for the frequency of events/mission quoted for the ships hull structure and the machinery. I would have expected propeller and shafting damage to have put this above average for the machinery, but the figure seems very high, conversely I would have thought the hull events/mission would have been higher. Can we be advised how such figures are arrived at. I should also be interested to learn what extent the crew affect the mission for reasons other than illness. The human is clearly more significant than might be supposed.

By Mr. M. Z. Navaz:

This paper has been presented in a similar form to the public at the Royal Institute of Naval Architects. I understand that it is also to be read at other public gatherings in the coming months. I wish the authors good luck in their presentation.

It is at the Technical Association's private meetings such as this that working Surveyors of the Society have a chance to comment on papers more frankly and freely—free from the administrative discipline of the office—on apparently radical approaches to the manner in which the Society's bread and butter is earned by offering a service to industry. A service fundamentally associated with the protection of life, property and the environment around the world where the engineering profile on installation design can vary considerably. Therefore one must be extremely careful that in a radical paper of this type, care is taken to cover all aspects of approaches towards safety, not neglecting the conventional manner in which the Society's services have been offered over the past 200 odd years.

The mathematical approach based on statistical data from a data bank is a well established process of evaluating Risk and Mortality rates as a comparative study indicative of a possible approach towards assessing risk and reliability, leading towards safety standards.

Let me say at this stage that there is also increased fear that this method alone has not led to totally safe installations. There are many glaring examples of major failures having occurred in spite of having conducted studies and evaluation based on the technique that the authors have proposed—installations from nuclear power stations to storage terminals. The public at large and others are more concerned with the establishment of an integrated safety study of all the interface activities and disciplines associated with the installation leading to a concept of overall safety. It is no use simply identifying and quantifying the risk and reliability values—there is a need to manage these items in order to ensure that a low profile is constantly maintained and improved upon as far as the identified risks are concerned. This management aspect of risk and reliability must start right from the stage of seeking planning permission to construction, completion, commissioning, daily operation, third party inspection, maintenance and hence to contingency planning in the event of a minor to major mishap. None of these

have been discussed in this paper as an aspect associated with events leading to the design of a total safe concept of an installation.

This paper must be looked upon in conjunction with the following previous three staff association papers:

(a) by Mr. Sullivan on the working of the TRO.

(b) the last paper by Mr. Beart on Computers.

(c) by Mr. Munro on Marine engineering failures,

together with many other related papers.

If the prime purpose of this paper was to illustrate the need for establishing a greater auditability in an orderly manner coupled with statistical data then the paper is a pointer in the right direction. The probability theories may contribute towards trends, but, as the paper's title indicates, it conveys only a part of the exercise in risk and reliability and safety assessment methods for ships and other installations.

The content of this paper suggests that the exercise is the authors' own handiwork. However this is not strictly true as many of the examples quoted in the Appendix are the joint work of a number of departments within the Society. It is also felt that the expert views and reasoning behind the departmental conclusions on safety assessment have not been wholly represented.

A co-ordinator should be able to effectively combine the work of various departments and present an overall picture reflecting all views. "The number crunching approach" has created doubts and suspicion in the minds of the lay public who by themselves are capable of engineering equally creditable figures to vindicate their alarms and fears.

The glamour of statistically generated data such as the 10^{-4}, 10^{-5}, 10^{-7} number game is wearing off if at the end of the day it is expected to play a useful part in decision making in establishing a confidence level associated with the populace and the environment and the success of the commercial venture. In the 1960's and 70's, the end product of this numerical value was extensively used as a smug standard which politicians, design ers, public bodies and the lay public used as a decision making tool in conjunction with fatalities curves. The end result, by playing around with the "and " and "or" gates, can bring about varying results in a fault tree audit as illustrated in the paper.

As regards statistical interpretation from a data bank, great care and prudence is required in one's interpretation of the data when involved with "Safety exercises" particularly being a Classification Society involved in a safety service industry, offering service in different parts of the world, to a variety of engineering industries motivated with objectives and philosophies that vary from one extreme profile to another. These profiles may refer to a host of items from environmental criteria, instrumentation, automation, manning levels, rich engineering hinterland, hard currency areas giving freedom to buy equipment in any part of the world etc., etc., to the other extreme ends or intermediate levels. The term risk and reliability and safety in all the above profiles is largely dependent on risk and reliability management at these installations.

Risk and reliability management may be defined as a systematic way of protecting the resources and income of an engineered installation and its organization against non-speculative risk in the most economic way. The safety exercise starts off with the fact that every engineering installation involves risk orientated modes. We first start off with two time related goals.

"PRE-LOSS"
"POST-LOSS"

Pre-loss objectives relate to the protection of life, property and the environment, the economy of the design and the avoidance of anxiety.

Classification wise—plan approval and inspection service associated with new building etc., etc.

Post-loss objectives relate to the speed and completeness of recovery.

Classification wise—AS, SS, CS, Interim Certificates, etc., etc.

I am not going to further indulge in clarifying the Society's role in the Pre-and Post-loss control objectives of risk and reliability management—it should be obvious to the Surveyors.

Risk and reliability management to maintain a low profile is the real exercise involved in an approach towards the establishment of a concept of "total safety".

The management towards the concept of "total safety" involves at least a five stage decision making process as follows:

1. Identification and analysis of all "Risk Potentials". The fault tree method is not always suitable—there are many other methods.
2. Formulate feasible alternative solutions. This aspect has not been identified as a possible solution in this paper —particularly for each risk potential.
3. Choose the apparent best alternative solution—again little or no comment has been made on this aspect.
4. Implement the chosen solution. The authors have failed to give credibility to the expertise of other specialised departments within the Society in the examples cited.
5. Monitor the results to see what further steps are needed to manage the risk/reliability potential in order to improve the designed low profile of such potentials.

These are some of the important basic steps followed by a number of subsidiary analyses.

How should the risk potentials be tackled?

There are generally four routines.

1. RISK AVOIDANCE (which is self explanatory)
2. RISK ABATEMENT
   i.e. by implementing Rules, Regulations, Codes, traditional safety and accident prevention and loss control procedures etc., etc.
3. RISK TRANSFER
   i.e. the sharing of risks and reliability norms e.g. standby equipment, dual circuits, spare gear etc., etc.
4. RISK ASSUMPTION
   This involves assuming the costs of any losses, either in ignorance or as a calculated decision, e.g. firefighting equipment, lifeboats, safety equipment, training and education, contingency planning.

All this then leads to the establishment of a planning process bringing together all interested and affected public and private bodies so as to ensure global participation towards environment protection of the populace to minimize the "post-loss" objectives related to the speed and completion of recovery.

Therefore risk, reliability and approach to total safety concepts are not new to the daily task undertaken by the Society's Surveyors. Whatever people may say about the Society's activities—ours is essentially a "risk and reliability management business". The words associated with an Interim Certificate issued by a Surveyor start with a recommendation to the Committee of Lloyd's Register of Shipping to continue to maintain the vessel in class. . . etc. Is this not a considered indulgence in a reliability and safety assessment exercise?

In conclusion I would like to recall a recent announcement of a Government's approval of the safety of a large hydrocarbon storage installation after having conducted a number of risk, reliability and safety studies. This was followed by the news media announcing that the safety proposals put forward by the Trade Unions and formulated by the people who work in the installation had not been implemented. This last statement will require a lot of public relations to dispel any fear or alarm it has created. It would be unwise to dismiss public monitoring bodies

as being generally uninformed or mischievously motivated.

An approach to total safety concepts cannot rest on number evaluation techniques alone—the end result of a study must motivate the removal of anxiety in all facets of operation of the installation throughout its working life. The study itself must bring about the participation of those who live in and around the installation. The number evaluation technique is only a thin veneer of the total study leading to safe concepts.

By Mr. F. Kunz:

The paper deals with concepts which are likely to affect the way in which the Society works. It should be carefully considered by all Surveyors and the authors deserve thanks for presenting it. Mathematical formulation of problems has rapidly entered many fields affecting everyday life and the paper shows ably just how far it has entered into the working area of the Classification Societies.

It is pleasing to find that a problem which exercised a number of surveyors in T.I.D. greatly about five years ago is still considered worthy of mention. The authors views would be appreciated on a number of issues contemplated at the time.

Mathematical manipulation of reliability and risk data is amenable to objective discussion, making the techniques irresistibly attractive. The same objectivity may however not operate during the original modelling of problems, particularly those involving safety of people or environments.

Moreover, in the more familiar fields, the dynamics of machinery and ships may change constraints or logic paths, because of interface interactions or simple wear and tear. A multitude of modifications are commonly introduced as new designs of machinery mature, not least because manufacturers estimates of service life are not always born out in practice.

Ultimately most machinery failure could be ascribed to the human element, but on a more practical level, blaming operators is an approach not totally unknown at present. The prospect of having it done by the Society's computer because no other explanation fits the programme constraints is somewhat daunting.

Presumably risk analysis of a given system is not a static once and for all exercise. What Classification procedures are foreseen to ensure that valid data is used in the assessments, and would the authors advocate simulation testing of machinery or structural details testing as used at present in some high technology fields?

By Mr. L. N. Heminway:

1. The subject of the paper which summarises techniques of risk and safety assessment and how they could be applied to the marine environment is important for future developments within Lloyd's Register.

   However, the basis for developing this approach is understanding the raw data (i.e. its source, how collected and what the count represents) as well as a thorough knowledge of the statistical techniques to be used and a correct interpretation of the results.

   In this respect I do not find the paper convincing and I would like to state why not, hoping these remarks will be useful.

2. In section 1 of the paper which quotes serious casualty incident rates recorded between 1968 and 1981 for IMO, the commentary "suggests that the incident rate . . . continues to increase . . ." This statement is supported pictorially by a trend line, which is one of many that can be fitted.

   Statistical analysis of the data does not support the hypothesis of a trend over the fourteen years and moreover, the recently released 1982 figure of 1.84 casualties per 100 tankers is lower than any of the previous years mentioned. In any case no cognizance is taken of changes in the structure of the fleet (e.g. age or size) throughout the intervening years. Overall there is much heterogeneity.

   It is relevant to quote from the IMO booklet containing these figures with regard to the background and definitions used.

   (i) Serious casualties include reports of:

   A fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, hull cracking or suspected hull defect resulting in: structural damage rendering ship unseaworthy such as penetration of hull underwater, immobilization of main engines, extensive accommodation damage, etc., loss of life; and/or pollution (regardless of quantity).

   A breakdown necessitating towage or shore assistance; or

   A total loss.

   (ii) Despite the explicit definition of a "serious casualty" the inclusion or exclusion of an individual incident is to some extent a subjective decision by the Group.

   (iii) Comparison between the casualty rates for the different categories of serious casualties should be made with care because incidents in some categories may be more likely to be classified as "serious" due to the nature of the definition.

3. Tables 8 to 10 in Appendix 2 give damage counts to all Gas Ships which are summated over a 19 year period. No definitions are given as to extent, severity or meaning of damage count. Nor is any distinction made between operator caused damage and what is found at survey. The latter counts are cyclical, peaking every four or five years so that one wonders over the interpretation and usefulness of an incidence rate per day. Further, the denominator is calendar time and not time underway so that the daily chance of damage due to collision or grounding is understated.

   Whereas damage to the hull structure contained in the classification survey reports is practically complete, similar reporting of defects on machinery items is almost invariably confined to what is found at survey. This makes most of the machinery information unsuitable for reliability purposes and accounts for the cyclical pattern of main boiler defect rates given in Fig. 17.

   It is important to define the criteria of failure for reliability purposes and to distinguish not only the severity but also between actual failures or breakdowns occurring during operation and potential failures found during maintenance or survey intervals. This latter point is obscurely referred to in the comments relating to Fig. 14.

   Although it is statistically acceptable to compare the data in Figs. 12 and 13—they are both collected from the same source and counted in the same way—the likeness should be extended to the "at risk" criteria. Incidence rates for main propulsion oil engines tend to increase with size. Engines of 1000 kW and over cover a vast range of power with the medium speed oil engine concentrated at the lower end and consequently indicating an apparently lower incidence rate than that for slow speed oil engines.

4. Appendix 7 dealing with the probability of ship collision is interesting but deals with penetration given that a collision occurs. Here the equation depends on the independence, which must be demonstrated, of P_c and P_0 and also on the derived KE distribution.

   If the value used for "t-knots" is the design speed then the probability of a ship having at least a certain KE is only relevent to a collision at sea. Less than two-fifths of the recorded collisions for the Serious Casualties to Tankers Analysis occurred at sea.

It is correctly stated that the probability of colliding depends on location and it is questionable as to the relevance of "a typical value" used in the example. Safety problems demand better preciseness even in an example.

Some useful work on the probability of ship collisions in the English Channel was published in 1974 by Macduff.

5. The mission simulator given in Appendix 5 is of necessity a brief account of the original exercise. But it seems hurried, inconsistent in places and lacking in basic definitions which, if clarified, would have assisted in understanding as to how the study was developed. Instead there is doubt as to the viability of the results as well as being an illustration of how statistics gets a bad name.

The FTA shown in Fig. 27 is stated to be typical, but so many of the incidence rates for groups of events are identical. This questions the source of the data and the usefulness of going into such detail.

The text states that Table 18 is an example of one 20 year mission, but the table only covers 10 years (58 events). Likewise Table 19 refers to a 20 year mission but lists 64 events. Fig. 28 gives a summary of simulation events over a 20 year mission and these appear to total 142. Finally to complete the confusion, Table 20 shows 359 as the number of events over 60 years.

Defining the severity of a failure to the ships hull structure or machinery would have enabled the practical surveyor to assess the validity of what was being attempted. It would seem from Fig. 28 and Table 20 that the number of machinery failures (shafting, engine, switchboard, FW cooling, SW cooling and power generation) averages three per year. This compares with over 11 main engine breakdowns per year referred to in Appendix 2, Fig. 14, page 19.

From Table 20 it can be calculated that the range of events per year, with 95% confidence, is between one and 11, the results shown in Table 18 lie within this range. Also the range of events expected over 20 years (average 120) is between 100 and 144. Fig. 28 gives an aggregate of 142 near the top end of the range. These are confirmatory checks on the figures quoted but in the light of other doubts it is wondered how many simulations were run and rejected as the randomness of the technique would make it unlikely for any two computer runs to produce identical results.

6. The last paragraph in section 5 (Reliability and probability) is correct given the theoretical concept of a constant failure rate and the occurrence of a random event. Also implied is the availability of complete information related to controlled conditions.

In the marine environment this unfortunately is not the case and there is much work to be done to quantify in a meaningful manner and subsequently analyse statistically occurrences to ships equipment, machinery and structure. But initially our work, in this field, has to follow what is generally accepted. It is relevant to quote section 7.3.11 of British Standard BS5760 part 2, which states:

"The forementioned distributions are extremely important when dealing with life data in that they can adequately model failures resulting from physical failure processes such as ageing, wear out and other general modelling considerations. However they should not be considered as exclusive. Considerable research both of a theoretical and physical modelling nature is still being undertaken. The impact on Reliability thinking as a result of these and future research projects is unquantifiable".

7. In appendix 1, the standard deviation (s.d.) of the log normal distribution should be:

Mean $(\exp(\sigma^2)—1)^{\frac{1}{2}}$

In appendix 6, the right hand column contains three errors.

(i) σ_s = standard deviation not distribution

(ii) $\sigma = (\sigma^2_s + 45^2)^{\frac{1}{2}}$ not $(\sigma^2_s — 45^2)^{\frac{1}{2}}$

(iii) The probability of failure is 0.025 not 0.175.

AUTHOR'S REPLY

To Mr. Rapo:

Quantitative reliability analysis techniques have in many organisations (and the Society is not unique in this respect) understandably taken time to be applied beneficially. It is very welcome to receive constructive comments from any quarter. In response to Mr. Rapo's first question the hard information presented in Fig. 1 is contained in the histogram. The trend line was chosen on the basis of a moving three year average so that particular factors affecting any one year were smoothed out. Other bases could equally well have been selected, one of which would have been an average of all years. In the Introduction the authors have tried to relate the background to the reasons why safety analysis techniques of the type discussed are important by presenting casualty information. The line was not deliberately rigged but if it has helped to reinforce the Introduction then so be it!

When the authors refer to the present methods used adequately for design appraisal, etc., but add a warning about avoiding complacency, it is intended to suggest that in the future there may be a need for a radical change to traditional methods in order to satisfy the Society's aims. It is considered that the methods described in the paper could be useful. The Society cannot afford to rely on traditional practices if these are no longer relevant to new technologies and projects being presented to the Society. Several research and development projects are in progress which are looking at alternative ways of establishing acceptance criteria. The programme of research has recognised the need to establish an enhanced data base of structural and component reliability data.

It is agreed that the interpretation of the results of a reliability analysis may appear to be the source of much scope for argument. Taken to the level suggested by Mr. Rapo, which is not uncommon in practice, when one figure is cited as being acceptable and another as not acceptable this is indeed the case. When the consequences of a failure are included and a "life cost" model established, it is often relatively straightforward to make an assessment of the optimum solution. Reliability practitioners are often guilty of quoting failure rates in terms of seemingly meaningless figures, usually without any units of time or any other conditional statements. However, within the Society, and indeed elsewhere, it is preferable to quote figures in comparative terms and avoid casting them in an absolute way, until the technology has gained further ground.

The use of values such as 10^{-7} or 10^{-6} in such a manner is to be discouraged. However, as Mr. Rapo notes in his comment on domestic fire alarms, the cost element may be obvious on an

intuitive basis and, hence, the failure rate figures may be directly comparable. There is undoubtedly a balance between cost and safety, which itself infers that there will be a level of safety that is cost-effective. It is suggested that the Society already intervenes in this matter of commercial judgement since many of our requirements must affect an owner's costs. The existence of Classification Society's must be due to the fact that, left to commercial judgement alone, the shipowners needed, and may be still need, cajoling to spend additional money in order to meet the minimum level of safety acceptable to the community.

The use of probabilistic risk assessment to justify the safety of high risk projects has indeed provoked opponents to use similar methods to demonstrate unacceptability. In many cases the basic argument is related to failure data. It follows that attention must be paid to the relevance of data and its statistical interpretation. There are, however, cases where errors have been found, usually in the form of omissions from fault trees. Disputes do, however, still arise over basic analytical techniques such as finite element methods so it is hardly surprising that a relatively new methodology provides scope for debate and difference. It does follow that it is wise not to be too categoric in the conclusions drawn from analysis and to use sensitivity and comparative analysis to test the importance of particular assumptions.

The pie chart (Fig. 29) which summarises the main activities of the simulated Arctic LNG Carriers is only an example for illustrative purposes. However, towing time shown is significant. Towing speeds and support arrival times for each phase and month are defined in the model. The requirement for tug/icebreaker support is triggered when, for a particular failure event, there is loss of power such that the minimum power required to operate the ship cannot be met. When the total power is recoverable by on-board repairs the ship remains stationary until such repairs are effected to enable the ship to proceed and no support vessels are required. When support is required the arrival delay time is dependent upon the position of the vessel. However, towing time is then the time taken to escort the ship to the required defined repair facility. Allowance was taken for the availability and disposition of the Canadian Coast Guard's 23 icebreaking ships. Of these, only two were rated as heavy icebreakers considered capable of mounting ship rescue operations in the high Arctic in winter. Because of the severe problems associated with the towage of the vessel in multi-year ice conditions, the sister ship of the icebreaking LNG carrier was considered the most effective solution to providing assistance in heavy ice in winter.

To Mr. Smedley:

The contribution from Mr. Smedley is most valuable, based as it is on many years involvement with what could be termed "classical failure analysis". The comments on casualty rates are most interesting. The authors had concentrated on ship incidents and so Mr. Smedley's notes on offshore installations form a useful source of additional material. His loss rate figures have been tabulated for convenience and compared with some recent results for ships. These are shown in Table 21 on a standard basis of 1000 unit years or 1000 ship years. The suggestion that a level of failure of 1 in 1000 unit years would require investigation on the establishment of likely causes (and presumably remedy) is interesting. Perhaps this figure is on the conservative side when considering the content of Table 21. However, unacceptable rates would need to be conditioned to reflect the consequence of the casualty. For example, the same loss rate may not be acceptable for LNG and LPG ships as for dry cargo ships (Table 21 shows that this is not the case).

TABLE 21

LOSS RATE COMPARISON OF OFFSHORE INSTALLATIONS WITH SHIPS PER 1000 UNIT OR SHIP YEARS

	Total Loss	Serious Casualty	Total Rate
Jack-Ups	13.29	14.58	27.87
Semi-Submersibles	6.51	5.43	11.94
Drill Ships and Drill Barges	3.82	5.73	9.55
Offshore Unit Totals	9.53	10.47	20.00
General Dry Cargo Ships	11.46	27.25	38.72
Ro-Ro Cargo Ferry	2.66	19.47	22.14
Ro-Ro Cargo	3.80	41.29	45.09
Vehicular Carriers	3.11	25.68	28.79
Container Ships	1.45	26.27	27.72
Bulk Carriers	3.58	30.12	33.70
Ore Carriers	9.01	24.22	33.23
Dry Cargo Ship Totals	8.98	27.71	36.69
LNG & LPG Ship Totals	3.79	16.73	20.52

It is agreed that feedback from service is essential to any designer or operator. Failures must be dealt with in perspective. Too many times it seems that various "loopholes" in safety related guidelines are closed following a single incident where the consequences were severe. In these circumstances the resultant action sometimes does not take account of the range of failures that could have resulted in a similar incident but only the specific failure identified in the post-accident analysis. It is suggested that the statistically based approach described by the authors can put accidents and failures into perspective.

Human error is always a problem to the reliability analyst, rivalled only by the rising star of software error. In their paper the authors have deliberately played down the subject of human error and concentrated on hardware failures since this is the area most under the control of the Society. However most failures have some contribution from human error and the various forms could be added to the check list given in Table 4. This would include errors in:

- Specification
- Design
- Material selection
- Fabrication
- Inspection and testing
- Operation
- Maintenance
- Decommissioning

In many cases the emphasis has been placed on operator error and the other areas have been neglected. It is difficult to quantify these forms of failure but in some areas reasonable estimates can be made. In others, noteably fabrication and maintenance areas it is contended that in overall terms when considering the typical behaviour of one of a large population of similar items human error can be considered as a characteristic of the item. This does not account for a noteably bad example but then much of reliability analysis is based on typical performance and aims to assess the likely service record rather than the specific results that are attained. Obviously, the casualty and damage data held by the Society includes most of the above forms of human error but they are very largely inseparable. The data certainly cannot place human error in full perspective yet.

Any detailed safety assessment is a lengthy process and can involve elapsed times of the order quoted. If a reliability analysis is conducted by the design team as part of the design optimisation process then the cost penalty is not, generally, large. Safety analyses are generally carried out by independent parties, either internal or external. The difference then between existing and new installations is small since the analysts must often try to identify the reasoning of the designer to discover the raison d'etre of the hardware arrangement. Any modifications must be viewed within the environment of the whole installation and the effect analysed. It is usual to find that the understanding of the capability of the ship and its machinery and its limitations is increased by such critical analysis. In many cases the costly analysis can identify areas where small investments can result in considerable enhancements in efficiency and operability. It may be of interest to refer to a recent example of the application of reliability technology to chemical tankers,[49] where the analysis included the effects of human error.

49 Clarke, B., Lewis, K. J. and Adam, J. C. "Comparative Hazard Analysis for Chemical Tankers with and without Inert Gas", Hull Structures Report No. 83/91, Lloyd's Register of Shipping, December 1983.

To Mr. Wills:

The principal use of reliability based analysis techniques within the Society, at least to date, has been in connection with consultancy activities. As Mr. Wills implies, these activities have tended to involve special purpose, high risk or unconventional designs. There is a division of opinion within the Society as to whether or not these statistical and probabilistic methods can play any part in the area of Classification, particularly in Rule Development. The authors are of the opinion that it will be increasingly important to be able to justify Rule formulations. Since it is generally accepted that no commercially acceptable safety guideline can preclude failures, it follows that the Rules must be satisfactory if the casualty rates are acceptably low. The use of limit state methods with safety factors that are meaningful in reliability terms is foreseen.

Where necessary some form of reliability demonstration could be required. In many machinery systems the assessment for Rule compliance is based on arrangement and capacity, rather than the strength type calculation that is amenable to limit state methods. In these cases a formal reliability analysis based on suitable component failure data may be suitable. Criteria for acceptance, where similarities exist, could be based on previously acceptable levels based on feedback from service and survey.

Mr. Wills has identified an important area that will no doubt provide plenty of scope for future debate and study. It is considered that, as a long-term aim, an increased use of reliability methods in consultancy projects and in Classification activities will be beneficial to the Society in continuing to provide a meaningful service to industry.

To Mr. Talbot:

The burden on TRO has greatly increased with the demand for failure data that has accompanied the use of reliability analysis techniques. The authors wish to endorse Mr. Talbot's remarks about the need for data beyond that provided by Classification survey reports. The periodicity identified in the various figures in Appendix 2 is just a part of the problem. The main concern is centred on the completeness of the service record. It appears that the data extracted from computerised planned maintenance schemes will fill in some gaps but the information does relate to maintenance operations and not failures. The information, therefore, relates to artificially-shortened component lives and in many cases no judgement can be made on the reason for the action described. The problems associated with failure data will no doubt continue to haunt the reliability analyst for some time yet.

The possible benefits of conducting any analysis are often questioned. The authors would suggest that the use of reliability analysis techniques would result in a more thorough assessment of hardware design, particularly with regard to interactions between components and systems. By the use of logical and critical assessment it is likely that some, if not all, of the shortcomings of a design could be identified and estimated. It is considered that safety improvement resulting in a reduction in casualty rates could be reasonably expected but no analysis technique could lead to elimination of all failures.

When considering and comparing risk levels there are without doubt difficulties and Mr. Talbot's reference to Fig. 8 emphasises this. The information in this figure relates to individual risks, and the zones can be described as those situations where the individual can exercise personal control, those where there is some degree of voluntary involvement and those where involvement is not subject to any individual control. Reactions to risk acceptance are obviously different in each case as shown in the figure.

When considering the information presented in Fig. 28 and Table 19 it is important to remember the details of the application. The prime movers used were six industrial gas turbines and a high failure rate was used by the analyst concerned. This accounts for the excessive contribution to failure of the machinery relative to the hull structure, containment system and outfit. Event predictions made in the simulation were based upon the MTBF, for each of the main systems analysed allowing for the ship's location and time of year, and the random number generation of the Monte Carlo method. This method is briefly described in Section 9 of the paper. It must be realised that crew effects other than crew illness and crew incident (e.g. negligence, incapacity, etc.) were taken into account in all fault trees developed for each of the main systems. The authors agree with Mr. Talbot about the significance of the human in assessing reliability and hence safety, and he may also be interested in referring to reference 49.

To Mr. Navaz:

As a point of clarification the paper presented by the authors to the Royal Institution of Naval Architects (4) and subsequent papers involving the authors at various conferences were very different to the present paper which has only been presented to the Technical Association.

The authors would agree with Mr. Navaz that the methods described in their paper would be of little use if the traditional methods of safety assurance were neglected. This point is emphasised by the authors in the introduction of the paper. However, it is considered that the formal, quantitative assessment of safety will lead to more rational decisions than the somewhat haphazard approach that relies entirely on the unquantified opinions of individuals, especially where no Rules or Codes exist. The authors have not intended to suggest that the techniques discussed should replace traditional methods but do consider that if the overall safety achievement is to be enhanced some form of quantum jump will be necessary which uses new methods.

It is accepted that certain exercises have resulted in the answer being interpreted, often out of context, in an irresponsible manner but this should not lead to unreasonable criticism of sound mathematical techniques by professional engineers and scientists. It is a question of presentation and it is suggested that recent studies have been more thorough and better received. With care it is possible to develop a well documented safety case with failure models correctly arranged and using failure data

relevant to the case of interest. It should not be possible to "play around with the 'and' and 'or' gates" as Mr. Navaz suggests since the installation operational parameters govern the failure model. It is noted that omissions may occur and specific failure routes may be unidentified but errors of omission exist in all analytical models. It is suggested that the enforced logical approach will result in the identification of several combinatorial failure events that may well be neglected by less rigorous assessment.

Mr. Navaz has been involved in many safety assessments, particularly with reference to refrigerated hazardous cargoes. The authors suggest that the techniques described in the paper could be beneficial to his work.

It has not been the authors' intention to claim responsibility for anything other than the statements made in the paper. The authors acknowledgement to the contribution of their many colleagues on page 13 was considered to be adequate. It was not the intention to reject the views of other colleagues.

To Mr. Kunz:

The problems of human error have been discussed in the response to Mr. Smedley and Mr. Talbot. It is practical to construct reliability of models for items that feature wearout and are subject to maintenance. These models become complex and are beyond the scope of this paper. Similar models could no doubt be introduced where modifications are incorporated during the service life.

It is imperative that any reliability analysis should be based on relevant failure models. After all, one would not consider designing a stainless steel component using carbon steel material properties. However, the piece of information that is really required is not available since future behaviour is usually considered and the only wholely relevant data has not been generated. It is important that the data used is derived from items whose operation was subjected to the same or similar conditions. Extrapolation and inference is often necessary.

It is possible to derive reliability data from test and this is the case in the defence industries. However, the sample is usually small and the duty cannot usually model all operating conditions. Testing, however, can be most useful as a source of data but it is costly and can only really be justified where the financial implications of loss are high or if mass production is anticipated. Testing is also long-term unless accelerated life or enhanced stress methods are used. In both cases there can be problems of interpretation.

To Mr. Heminway:

Mr. Heminway has contributed significantly to the collation and interpretation of failure data in the Society and his contribution as a professional statistician is most welcome. As such the authors accept most of his remarks concerning the statistical element of the paper which provides a valuable addition to the paper.

Several comments relating to the mission simulator described in Appendix 5 have been raised by Mr. Rapo and Mr. Talbot but it is correct to note that this is a very brief taste of a major study (incidentally, the study was reported in six thick volumes). Any simulation exercise can be misleading to people not intimately involved. As indicated no two simulations will give the same results and it is unlikely that the simulation results will be achieved in service exactly. However, very valuable sensitivity studies can be performed to identify important elements in a design and also to perform comparative analyses. It is a powerful tool that permits realistic life modelling. In this way it is possible to assess the likely effects of changes in a design without the need to wait, possibly for several years, for the feedback of service data.

It is presumed that Mr. Heminway's comment relating to Section 5 refers to the last paragraph on page 5. It is agreed that constant failure rate concepts may not be adequate models for marine components where wearout phenomena undoubtedly exist. It is likely that better distributions will be used when better data is available in the future.

ERRATA

The following corrections should be noted:

1.	Page 11	Col. 2 Para 3. Slovik should read "Slovic".
2.	Page 12	Fig. 10. Title "fatal" should read "fatality".
3.	Page 14	Ref. 37. Slovik should read "Slovic".
4.	Appendix 5	Second para last sentence "Unconfirmed should read "unconfined".
5.	Appendix 1	mean exp $[(\sigma^2) - 1]^{\frac{1}{2}}$ should read mean $[\exp(\sigma^2) - 1]^{\frac{1}{2}}$
6.	Appendix 6	σ_s = Standard deviation and not distribution.
7.	Appendix 6	$(\sigma_s^2 - 45^2)^{0.5}$ should read $(\sigma_s^2 + 45^2)^{0.5}$

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